■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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OF INTEREST TO MANAGERS

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Chinese Mitten Crab As a Potential Host for Lung Flukes. p. 12–13. Walter and Culver discuss the potential for the recently established Chinese mitten crab to serve as an intermediate host to human parasitic lung flukes. It is presently unknown whether North American or Asian lung flukes occur or could become established in mitten crabs within the San Francisco Estuary and associated watershed. No lung flukes have been found in the 500 adults examined, however, juvenile crabs and other crustaceans have not been examined.

Understanding Reproductive Development of the Chinese Mitten Crab. pp. 13–16. Tsukimura and Toste describe their work to develop indicators of reproductive state in mitten crabs. Understanding the processes that regulate the onset of reproduction could lead to identification of the stimulus (e.g., water temperature or day length) initiating downstream migration of crabs. If these stimuli can be monitored or predicted, it may be possible to anticipate the onslaught of migrating crabs, which could minimize the crab's threat to fish salvage operations at the SWP and CVP.

Water Quality Results from San Francisco Bay. pp. 17–20. Buchanan presents times series data of specific conductance, water temperature, and water level collected at seven sites in San Francisco Bay during water year 1999. Graphical results show tidal variability (ebb and flood) and seasonal differences strongly influence these data.

The Benefits of Floodplain Habitat to Rearing Chinook Salmon. pp. 26–30. Sommer and others present results of a study comparing the value of floodplain and riverine habitats to rearing chinook salmon. Study results indicate that salmon rearing on the Yolo Bypass floodplain have better growth, feeding success and perhaps survival than those which migrate through the heavily channelized Sacramento River. Results from these sorts of studies can help determine priorities for habitat restoration in the estuary.

Primary Food Resources in the Delta. pp. 21-25. Jassby and Cloern present a summary from their work examining the quantitative importance of different organic matter sources and some of the factors affecting temporal and spatial variability. Differences among sources were found among water years and seasons. Spatial heterogeneity implies that the relative importance of various sources will differ among subregions of the Delta. The results demonstrate that flow management has profound effects on the supply of organic matter to Suisun Bay, an important nursery area for larval fish. Moreover, these results underscore the need to obtain a better understanding of Delta ecology and the underlying processes to help guide the substantial restoration efforts contemplated for the Delta.

Monitoring the Distribution and Migration of Delta Smelt Using a Midwater Trawl. pp. 31–36. Gartz reviews the DFG midwater trawl (MWT) survey and its ability to provide useful information about the abundance, distribution, and spawning migration of delta smelt. This article provides a thoughtful discussion about the limitations of the MWT survey and the challenges to addressing those limitations. The article concludes with several recommendations for changes to this survey.

Largemouth Bass Fishery in the Delta. pp. 37–40. Analyzing tournament data from 1985–1999, Lee shows a remarkable increase in the number of bass tournaments and angler effort devoted to catching bass in the Delta over the last 15 years. The Delta Bass fishery has shown improvements not demonstrated by other California black bass fisheries. This article clearly demonstrates that other fishes besides the natives (delta smelt, salmon, and splittail) we hear so much about are also important.

Estimating Population Level Effects on Salmon and Estuarine Species. pp. 41–54. Miller presents a provocative article describing methods for estimating the population effects of changes in river flows and Delta water project operations on several important species of fish. Such approaches could have application in estimating the benefits of using water from an environmental water account or other actions to mitigate the impacts of water project operations.

Letters to the Editor

Standardized Terms for IEP Publications:
A Hindrance or Help for Communicating the Value of IEP Work?

Regarding Wim Kimmerer's suggestions for standardized communications in the *IEP Newsletter* (spring 2000 issue): I concur with Wim about using the terms, "San Francisco Estuary" and "Sacramento-San Joaquin Delta." However, I do not agree that the *IEP Newsletter* should use metric units. Wim argues that the *IEP Newsletter* and IEP technical reports are about scientific issues and that the language of science includes a common system of units which is entirely metric.

I think Wim is going in the wrong direction with that suggestion. I do not think the *IEP Newsletter* or technical reports have a problem of not being scientific enough. Their problem is the opposite—about 80% of the IEP's funds come from the state and federal water projects. These projects are interested in information that is timely and relevant to the problems of the San Francisco Estuary in general and the Sacramento-San Joaquin Delta in particular. The IEP is doing a progressively better job of satisfying that need.

Randy Brown's "Of Interest to Managers" inside the front cover is a big step in the right direction. I would like to see even more emphasis on the management relevance of IEP work, and that emphasis appears to be forthcoming.

I would argue that the *Newsletter*'s departure from the normal rules of scientific publications is what makes it so valuable. Information is timely. Ideas can be presented and then debated in later issues. And, we don't have to convert the numbers to another language. (Incidentally, when Ron Robie was DWR Director, there was an attempt to go metric. It did not work.)

If we have to use metric units to gain scientific respectability (the appropriate amount of which I do not believe is lacking), then follow the English units with metric units in parentheses, but please don't start producing graphs that require all of us to convert to acre-feet or cubic feet per second before we can appreciate their relevance.

William J. (B.J.) Miller, Consulting Engineer

Editor's Note: *The IEP Coordinators discussed the issues raised by Kimmerer (spring 2000 issue) and again here by Miller. The Coordinators agreed to adopt the terms proposed by Kimmerer as the standard terms for the IEP. The term "San Francisco Estuary" includes the San Francisco Bay and the Sacramento-San Joaquin Delta.*

Beginning January 2001, the full name for the IEP will be the Interagency Ecological Program for the San Francisco Estuary. The Coordinators also agreed that Standard International (SI) units will be the primary units of reported measurements for all IEP work including IEP Newsletter *articles. Other units may be added in parentheses after the SI units. This change will also take effect January 2001.*

INTERAGENCY ECOLOGICAL PROGRAM QUARTERLY HIGHLIGHTS—SUMMER 2000

BLOOM DETECTED IN STOCKTON SHIP CHANNEL

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Bay-Delta Monitoring and Analysis Section staff detected a brief and moderately intense phytoplankton bloom in the Stockton Ship Channel in the eastern Delta on May 22. The bloom was located in the vicinity of the multi-parameter recording station in the San Joaquin River at Burns Cutoff, near the western end of Rough and Ready Island.

Staff conducted a follow-up study of the central and southern Delta on May 25 to further clarify the extent and intensity of the bloom. The bloom extended from the San Joaquin River at Buckley Cove to the Stockton Yacht Harbor at the extreme eastern end of the Stockton Ship Channel and consisted of several phytoplankton taxon, with *Cryptomonas* being the most dominant organism. Other taxa present included *Thalassiosira eccentrica*, *Aphanizomenon flos-aquae, Cosinodiscus,* and an unidentified flagellated green algae.

Water quality was also evaluated in the bloom area to characterize conditions. Surface water temperatures ranged from 23.2 °C in the San Joaquin River at Channel Point to 25.1 °C at the Stockton Yacht Harbor. Fluorometric values ranged from 42.4 fluorescence units at the Stockton Turning Basin to 146.2 fluorescence units at the Stockton Yacht Harbor. The spectrophotometric values of chlorophyll a and pheophytin measured at the Stockton Yacht Harbor were 51 and 79.2 µg/L, respectively, and were 26.7 and 21.1 µg/L, respectively, at Channel Point. Nephelometric turbidity units (NTU) ranged from 6.2 NTU the Stockton Yacht Harbor to 10.6 NTU at the San Joaquin River at Buckley Cove. Finally, surface specific conductance values ranged from 413 µS/cm at the end of the Stockton Yacht Harbor to 475 µS/cm near the San Joaquin River at Buckley Cove.

Increased light intensity, warmer water temperatures and lower San Joaquin River inflows that typically occur during late spring and early summer may have been a stimulus for this bloom. The high production typical of the Stockton Turning Basin and Yacht Harbor may have also contributed to the introduction of the bloom into the San Joaquin River.

NEOMYSIS AND ZOOPLANKTON

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As usual, the native *Neomysis mercedis* was not abundant during the spring. Highest abundance in April was slightly more than 1/m^3 in the Suisun Marsh sloughs. Abundance was somewhat higher in May; the maximum was 10/m^3 in the lower San Joaquin River and 8/m^3 in Suisun Slough. The exotic *Acanthomysis bowmani* was much more abundant and reached 361/m^3 at Martinez and 277/m^3 in the low salinity zone.

As usual, the exotic *Limnoithona tetraspina* was the most abundant copepod, reaching highest concentrations in western Suisun Bay and in Carquinez Strait. The maximum was about 157,000/m^3 at Martinez in May. *Eurytemora affinis* was widely distributed but did not exceed more than a few hundred per cubic meter at any location. The exotic *Pseudodiaptomus forbesi* was also widely distributed and more abundant than *E. affinis*. It reached a maximum abundance of about 2,500/m^3 in Disappointment Slough. The native *Diaptomus* and *Cyclops* and the exotic *Sinocalanus doerrii* were not abundant but the native *Acartia* reached more than 35,000/m^3 in Carquinez Strait. This is the highest seen in several years. Cladocerans were not abundant except in the San Joaquin River at Stockton in April. Rotifers were only moderately abundant.

DELTA SMELT

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A special delta smelt vertical migration study was conducted on April 26–27, 2000, near Jersey Point on the San Joaquin River. Larval fish were sampled at three discrete depths using 0.5 m diameter conical plankton nets: one net was towed at the surface, one towed halfway to the bottom, and one towed near the bottom. Ninety samples were collected over a 17-hour period. To date, less than half of the samples have been processed. It appears larval osmerid densities were low. Preliminary results suggest there was a slightly higher catch of osmerids at the mid-depth than at the surface or bottom. Three times as many smelt were caught at night than during the day, and there seems to be no difference in catch between tides. The final data analysis will be completed this fall.

In May and June, high delta smelt densities near the CVP and SWP Delta export facilities resulted in the "red light" take limit being exceeded. Densities began to decline towards the end of June. To determine the "real time" distribution of delta smelt, three extra surveys (special surveys) were added to the normal 20-mm Survey. This resulted in weekly 20-mm Survey data from May through the middle of June.

Juvenile delta smelt monitoring by the 20-mm Survey has conducted 10 surveys (7 scheduled and 3 additional) through the middle of June. Preliminary results suggest minor spawning occurred in the central and southern Delta (surveys 1 and 2) and increased throughout the Delta (surveys through 6). Although the initial spawning was indicative of a wet year, catch from the latter surveys shows a trend similar to that of a dry year. Spawning incidence could be attributed to fluctuations in water temperature. High delta smelt densities (>1,000 fish per 10,000 m^3) appeared in June around the confluence. For additional information, access our website at http://www.delta.dfg.ca.gov/data/20mm/2000.

North Bay Aqueduct larval fish sampling continues. The lab processing of these samples is lagging by several weeks due to the higher priority of processing 20-mm Survey samples. It appears some delta smelt spawned in the north Delta. So far this year, we caught more delta smelt (274) than the last two years combined (54). More than 75% of the delta smelt larvae were from the stations around Prospect Island. Several delta smelt were caught in Barker Slough in April and May of this year, compared to none in the past two years. Wakasagi numbers are also much higher than previous years, access our website at http://www.delta.dfg.ca.gov/data/nba/2000 for more information.

REAL TIME MONITORING

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The Real-time Monitoring (RTM) program is approaching the end of the 2000 season. Monitoring began in late March and will finish June 30. Kodiak trawling at Mossdale continues as one of three maintained sites for the RTM 2000 survey. Trawling effort began on April 3 and will continue five days per week until June 30. Midwater trawls at Sherwood Harbor (Sacramento) and Chipps Island have been reduced to three days per week due to low tagged salmon catches, and increased numbers of delta smelt. This year RTM provided additional 20-mm surveys (special surveys 10, 11, and 12) which were conducted the weeks of May 7, 22, and June 5. Data from these surveys can be found at http://www.delta.dfg.ca.gov/data/20mm/2000/.

Light trapping for larval delta smelt began in March and continued through the first week in May. Surveys were conducted in Victoria Canal, Old River above Clifton Court, Miner and Cache sloughs, Old River at Frank's Tract, Turner and Columbia cuts, Grant Line canal, the North and South forks of the Mokelumne, Connection and Threemile sloughs, Empire Cut, Mandeville Tip, and Decker Island. The first delta smelt larvae were collected on April 6 in Turner cut. The largest concentration of delta smelt larvae were collected on April 20 in Victoria Canal and the Old River site above Clifton Court. Light trapping found post-hatch delta smelt distributed primarily in the central and south Delta.

Data from RTM light trapping, Kodiak and midwater trawling, 20-mm Survey, the spring midwater trawl and the federal beach seine surveys are available at the DFG website at http://www.delta.dfg.ca.gov/.

DELTA FLOW MEASUREMENT

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The twelve stations of the continuous flow-monitoring network collected data throughout the quarter without extended periods of missing data, except for the Threemile Slough station. As reported last quarter, the attempt to calibrate the SL-ADCP at Threemile Slough was not successful, therefore, on May 10th, a UVM was reinstalled at the site. Several sets of flow measurements will be made during June and July to flow calibrate the new UVM.

Tidal and daily flow data from the UVM and SL-ADCP stations should become available in near real time during next quarter from a website under development by the USGS. This new website will also have a link to the new hydrodynamics database, also being developed by the USGS. The new database will replace the old FORTRAN-based database that has been in use for the last 15 years or so, and will contain historical UVM and UL-ADCP flow and stage data, plus assorted other data for the Delta and Bay.

SPLITTAIL INVESTIGATIONS

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The quarter began with hiring Scientific Aids and preparing for field sampling. The quarter ended with preliminary sampling and modest changes to our approach for habitat measurement in our study of age-0 splittail habitat use in the Sacramento River. Initial plans to use a differentially corrected GPS (DGPS) to measure habitat area were bolstered by the recent elimination of selective availability (intentionally introduced error in the satellite clocks that reduced location accuracy), but in practice, errors in accuracy were still ± 5 to 10 m, too high for this study. Instead, we will (1) use DGPS to locate habitat center-points, (2) record range and bearing to habitat boundary points, and (3) map and calculate surface area of each habitat in ArcView. Preliminary fieldwork indicates a good splittail year class despite the abrupt reduction in March outflow that drained most floodplains. We expect year-class size is sufficient to allow detection of differences in habitat use. One indication of a good year class occurred the first day of field training when over 300 age-0 splittail were captured in a single 15-m beach seine haul. Fieldwork will continue through September.

Microsoft Access queries were completed to calculate age-specific splittail abundance indices for Bay Study otter and midwater trawl data, USFWS beach seine and Chipps Island data. This should reduce the time necessary to produce these indices in the future, barring any significant modifications to any of the databases.

JUVENILE SALMON MONITORING

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Seining at the lower Sacramento River sites collected 110 fall/spring run. The north, central, and south Delta catches included 590 fall/spring run. The San Joaquin River beach seine captured 39 fall run chinook, and the San Francisco Bay area beach seine caught one fall run on April 3 at Paradise Beach. Beach seine catches of juvenile chinook were down from those during the January through March 2000 period.

At Sacramento, the midwater trawl captured 2,691 fall/spring run. Kodiak trawling at Mossdale continued with DFG, Region 4 conducting the sampling. A total of 1036 chinook was captured. Midwater trawling at Chipps Island captured 17,761 fall/spring run and 50 winter run with the last one collected on May 20. The high Chipps Island fall/spring numbers were partly a result of double effort (20 tows per day) between April 16 and May 20 as part of increased tag recovery efforts for VAMP studies. While no late-fall run were captured in the trawls and winter run numbers declined, numbers of fall/spring run were lower than the previous quarter only at Sacramento. Mossdale fall run catches increased by 681 and Chipps Island fall/spring numbers were 17,658 greater than the previous quarter.

Catches of wild (non-adipose-clip) steelhead increased from the first quarter of the year, most of these were at Chipps Island where 41 steelhead were captured (181 to 447 mm). The Sacramento midwater trawl captured one steelhead at 215 mm, and three were captured in the Mossdale Kodiak trawl between April 7 and April 21 (240 to 287 mm).

This year, the Delta sub-team of the Salmon PWT is conducting a thorough review of the Delta Juvenile Salmon Monitoring Program and a report is expected soon. Several additional sampling efforts are recommended, such as year-round trawling at Mossdale, and a doubling of effort in the Delta and lower Sacramento River beach seines during the winter months. In addition, several cutbacks may be recommended, such as a reduction in effort of the midwater trawl at Sacramento during the spring.

For a review of the 1999–2000 Delta fisheries data, access the USFW– Stockton monitoring summary report at http://165.235.108.8/usfws/monitoring/report.asp.

SPRING MIDWATER TRAWL SURVEY, MIDSUMMER TOWNET SURVEY, AND FALL MIDWATER TRAWL SURVEY

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The Spring Midwater Trawl (SMWT) survey monitored the distribution and abundance of delta smelt (*Hypomesus transpacificus*) from January to March 2000. Results indicated that delta smelt were primarily located in Suisun Bay and Montezuma Slough. Monitoring was considered adequate despite the limitations of the gear and boat breakdowns in January.

The 2000 Midsummer Townet Survey (TNS) started on Friday, June 23, maintaining the continuity of the longest running survey in the Sacramento-San Joaquin Estuary. Results from the survey will be available on the Internet by late August or early September.

ROCK SLOUGH MONITORING PROGRAM

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A sieve-net was used to sample fish entrainment once a week at the Rock Slough intake of the Contra Costa Canal in April, May, and early June. The only fish captured in the sieve-net were three chinook salmon (*Oncorhynchus tshawytscha*) on May 3. All three salmon were within the fall-run size category for chinook salmon. Sampling was discontinued from May 8 to 22 due to a no diversion period at all of the Contra Costa Water District intakes. The sieve-net sampling will be discontinued in the late summer when the early phases of construction of the new fish screen facility begin at the Rock Slough intake. Fish entrainment sampling will resume when the initial construction period ends.

OLD RIVER FISH SCREEN FACILITY (LOS VAQUEROS) MONITORING PROGRAM

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A sieve-net was used to sample fish entrainment three times a week behind the fish screens at the Old River Fish Screen Facility in April, May, and early June. The only fish captured in April were those that were entrained at the larval stage and had grown up within the facility. Sampling was discontinued from May 8 to 22 due to a no diversion period at all of the Contra Costa Water District intakes. Although only a few larval fish were entrained in May, large numbers of larval fish were entrained in early June. Striped bass, *Morone saxatilis* (mean fork length 10 mm), was the predominant larval fish species captured in the sieve-net in June. One delta smelt, *Hypomesus transpacificus* (18 mm FL) captured on June 2 was the first delta smelt captured behind the fish screens since inception of the facility. An egg and larval net was also used to sample fish entrainment behind the fish screen starting in June; however, very few fish have been captured in the net.

SAN FRANCISCO BAY FISHERIES MONITORING

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The IEP, through DFG's San Francisco Bay Study, has been monitoring the abundance and distribution of fishes and macroinvertebrates in the Bay since 1980. Spring catches are a preliminary indication of year class strength for many species, although we typically use at least six month's data to calculate annual abundance indices. Age-0 longfin smelt catches from April through June 2000 were relatively low for the study period, with a total catch of 280. By comparison, we collected 1350 age-0 longfin smelt during the same months last year. However, catches have been much lower, with less than 100 age-0 longfin smelt collected annually from 1988 to 1992. In 2000, age-0 longfin smelt were distributed from Central San Francisco to Suisun bays, with the highest catches in Central San Francisco Bay in May and Central San Francisco and San Pablo bays in June.

Age-0 Pacific herring catches from April through June 2000 were the highest since 1993. (Note that in 1994 we dropped the midwater trawl from our survey after April.) With over 4,100 age-0 fish, the year 2000 catch was approximately seven times greater than either the 1998 or 1999 catches. The early cohort reported in the previous highlights article was still present in April, with fish from 65 to 80 mm FL. Fish from this cohort have been aged by Mike O'Farrell, a San Francisco State University graduate student. His preliminary analyses indicate spawn dates of October 20, 1999, and early November, which is very early for this species. Most age-0 Pacific herring were collected from northern South Bay and Central Bay, with a few fish as far upstream as Suisun Bay.

The first age-0 Dungeness crabs were collected in May, with a May-June total of 122 crabs. This is slightly higher than the 1999 May-June catch of 90 crabs; the 1999 age-0 index was the highest since 1988, which had an exceptional year class. In May 2000, age-0 Dungeness crabs were concentrated in the channel from northern South Bay to lower San Pablo Bay, but by June, they were dispersed over the shoals and collected from south of the Dumbarton Bridge to upper San Pablo Bay.

In contrast to the apparent revival of several cold water species, such as Pacific herring and Dungeness crab, our catches of some subtropical species, such as Pacific sardine, have declined. To date, we have collected only two Pacific sardine in 2000, compared to 831 fish during the same period in 1999. Also, no age-0 California halibut have been collected in 2000; in the first six months of 1999, we collected over 200 age-0 fish. The strong La Niña of 1999 dissipated in early 2000 on the West Coast, as sea surface temperatures have been near or slightly above average since January. Access the NOAA El Niño Watch website (http://cwatchwc.ucsd.edu/elnino.html) for more information about West Coast ocean conditions.

ADULT STRIPED BASS MONITORING

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Biennial tagging of legal-sized striped bass (>42 cm FL) was performed this spring. Striped bass were captured with two gill-netting boats in the western Delta (April 3 to June 1) and nine fyke traps in the Sacramento River near Knights Landing (April 19 to June 16).

We tagged 11,070 striped bass, the most since 1974. Before 1982, the legal size limit was 38 cm FL. If tagging had included fish from 38 to 41 cm FL this year, the total would have been approximately 12,671 compared to 13,785 in 1974. The number of striped bass tagged in the 1990s ranged from 4,612 (5,426 with 38 to 41 cm FL) in 1992 to 8,375 (9,821 with 38 to 41 cm FL) in 1991. In the 1980s, the highest number tagged was 7,403 (7,868 with 38 to 41 cm FL) in 1985. From 1969 to 1979, the number tagged ranged from 4,253 in 1978 to 18,377 in 1972 (>38 cm FL).

Of 11,908 legal-sized striped bass observed this spring, only 30 were recaptures from previous years. Twenty-nine were from the last tagging in 1998, and one was tagged in 1994. Coded-wire tags from net-pen-reared fish released into San Pablo Bay as yearlings or two-year-olds were found in 2.7% of the sublegal fish and 2.5% of the legal fish. The last time we tagged striped bass, in 1998, coded-wire tags were found in 0.8% of the sublegal fish and 2.4% of the legal fish.

This year's catch appears to have been dominated by three- and four-year-old striped bass (ca. 42-60 cm FL; 1997 and 1996 year classes), but an estimate of the actual age composition and abundance must await age determination of the tagged fish. The apparent high abundance of these year classes was not observed in the townet or midwater trawl surveys; however, the abundance is consistent with generally favorable estuarine hydrology.

Salmonid catch during striped bass tagging in 2000 included 51 adult chinook salmon and 17 adult steelhead. Forty-eight of the salmon were bright and likely to be spring run; the other three were more mature and were probably winter run. At least ten of the steelhead were hatchery-produced fish, as evidenced by adipose fin clips. These results compare with recent adult chinook salmon catches of 13 in 1998, when only the gill nets were fished, and 26 in 1996. Steelhead were not formally recorded before 2000.

Developing a Key for Larval Osmerids

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Wakasagi larvae were successfully cultured from an adult stock collected from San Luis Reservoir. Wild wakasagi larvae were also collected from San Luis Reservoir. A portion of the wild collected larvae was confirmed as wakasagi through genetic analyses. Over the next several months, we will document the variability of hatchery and wild wakasagi larvae using morphometric analyses. These characteristics will be compared with those of delta smelt larvae cultured and supplied by the Delta Smelt Culture Project. Additional wild specimens of delta smelt will need to be collected in 2001. Once enough specimens are collected we will begin to validate the key through a series of blind assessment trials with trained and untrained personnel.

Identifying the Trophic Structure and Carbon Sources of Fishes in Tidal Wetlands of the Sacramento-San Joaquin Delta

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The purpose of this project is to elucidate the trophic structure and source of organic matter that is ultimately assimilated by fishes along littoral zone (e.g., intertidal and subtidal habitats) and open water habitats (channel and deep subtidal) using stable isotope analysis. I anticipate this project will provide baseline information on how energy flows between primary producers and fishes in the Delta. Macrophyte, phytoplankton, invertebrate, and fish samples were collected at Mildred Island, Venice Cut Island, and Sherman Lake earlier this year. Over the next few months I will continue collections at these sites. Laboratory work will begin in August.

Exposure of Delta Smelt to Dissolved Pesticides

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This project is measuring the exposure of delta smelt to dissolved pesticides during egg, larval, and juvenile stages for the third year. Sampling began at the end of April with water collected at six Delta sites every two weeks (coinciding with DFG's 20-mm sampling) and analyzed for dissolved pesticides. In addition, periodic "burst" sampling is being conducted in Montezuma Slough to establish a pesticide-salinity relationship over time. Study results for 1998 and 1999 will be presented in an *IEP Newsletter* article being planned for the fall 2000 issue.

Knights Landing Juvenile Salmonid Monitoring

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Juvenile salmonid emigration monitoring at Knights Landing continued through the spring period, April through June 2000. Juvenile salmon and steelhead catches at Knights Landing fell to zero during the latter part of this period marking the end of the primary migration season. Salmon emigration essentially ended during the week of June 12. Steelhead emigration ceased over a month earlier in mid-April.

During the quarter, we captured 794 fall-run sized, 41 spring-run sized, 10 winter-run sized and 3 late-fall-run-sized chinook salmon. Nearly all of these salmon were collected during April, immediately following the first large release of Coleman National Fish Hatchery (CNFH), produced fall run into the upper Sacramento River. As observed during the past four years, the last catches of steelhead, and winter-run and late-fall-run chinook salmon at Knights Landing are associated with the first, large release of CNFH salmon. Seven steelhead, three late-fall run and nine winter run were captured at Knights Landing shortly after the CNFH release, while no steelhead, late-fall or winter-run salmon were collected for at least four weeks prior.

Overall, catches of both salmon and steelhead were low during the 1999–2000 season, less than half of the mean catch (about 60,000 salmon) observed during the first four years of monitoring at Knights Landing. Altogether, we collected 23,531 salmon and 38 steelhead, including 23,435 fall-run, 185 spring-run, 75 winter-run, 45 late-fall-run and 60 adipose-clipped salmon, and 27 adipose-clipped steelhead.

SHERMAN ISLAND AGRICULTURAL DIVERSION EVALUATION

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This element will compare the relative abundance and species composition of fishes entrained in side by side diversion siphons (one screened, one not screened) in Horseshoe Bend on the lower Sacramento River. The siphons are being sampled using modified fyke nets (1600-µm mesh) that sample all of the water coming through the siphons. We are planning to do a continuous 48-hour sampling blitz (consisting of hourly samples) from water being diverted through both the screened and unscreened siphons simultaneously. This initial field work will take place sometime during the first two weeks of July, but the specific dates have not been set.

UPPER ESTUARY CHINESE MITTEN CRAB RESEARCH PROJECTS

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Few Chinese mitten crabs have been collected in the Sacramento-San Joaquin Delta this year, although mitten crabs remain very abundant in South Bay tributaries. Mitten crab catch for the Chinese Mitten Crab Habitat Use Study remains low with only three crabs collected since February. Alternative sampling methods (for example, burrow excavation, beach seine, and modified crab scrape) will be explored in July and August.

The Mitten Crab Benthos Impact Study also has collected few mitten crabs. Sampling began in late April and has consisted of monthly otter trawls at nine stations. These stations are part of DWR's historical benthic monitoring stations. Data obtained from these initial trawls will be used to determine the presence of mitten crabs at the stations. Two crabs have been collected to date, one 46-mm male crab was collected in Suisun Bay near Martinez (D6), and a second 57-mm male crab was collected in the Sacramento River at Collinsville (D4). Both crabs were collected on May 18. A 425 mm green sturgeon, *Acipenser medirostris*, was also collected at D4 on May 18.

Interestingly, an age-0 crab (4 to 5 mm CW) was collected in the Yolo Bypass toe-drain in June. The crab was found amongst leaves in the rotary screw trap located 14.5 river miles upstream of the bypass confluence with the Sacramento River near Rio Vista.

DELTA SMELT CULTURE UPDATE

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Nearly 120,000 eggs were collected this season, yielding over 50,000 larvae. Most of the eggs were spawned during March and April, while temperatures were still cool. Smelt in the outdoor tanks (natural lighting) started spawning earlier and produced nearly twice as many eggs as fish from the indoor tanks (dim artificial lighting). As the outside temperature rose during May and June, water flows had to be reduced in all tanks. This was done to maintain 16 to 18 °C and may account for the reduced spawning activity during this time.

The smelt culture facility is now equipped with three recirculation systems fur use in larval/juvenile research. Experiments are still in progress to investigate the effect of stocking density (20, 40, and 80 larvae/L) and temperature (14 °C, 17 °C, and 20 °C) on growth and survival of smelt larvae. In addition, small-scale studies are being performed to follow up on last years feeding behavior experiments.

VAMP 2000 FISH INVESTIGATIONS

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The VAMP 2000 juvenile chinook salmon survival investigations have been successfully completed. The survival studies included a series of mark-recapture tests in which coded-wire tagged juvenile chinook salmon, also marked with an adipose fin clip, were released at various locations within the San Joaquin River and recaptured in fisheries sampling at downstream locations near Antioch and Chipps Island (Figure 1). After considering a variety of factors, the VAMP Technical Work Group modified the VAMP 2000 studies to incorporate refinements designed to improve the fisheries program, including relocating the upstream release location for marked salmon from Mossdale to a point approximately 11 miles farther upstream in the San Joaquin River at Durham Ferry. The Durham Ferry release location is expected to be used as part of the VAMP program in all years, with and without installation of the Old River Barrier.

As part of the VAMP 2000 investigations an additional group of marked salmon was also released at Mossdale to provide comparative survival estimates for juvenile chinook salmon, produced in the Merced River Fish Hatchery, released at Durham Ferry (the new VAMP release location) and at Mossdale, which has been used in previous San Joaquin River salmon smolt survival studies. Additional releases of marked fish were made downstream at Jersey Point (controls) to test the collection efficiency of the recapture sampling methods. One additional release of marked salmon, produced in the Mokelumne River Fish Hatchery, was made this year within the lower Mokelumne River near the confluence with the San Joaquin River to provide additional information on salmon smolt survival within the central Delta region.

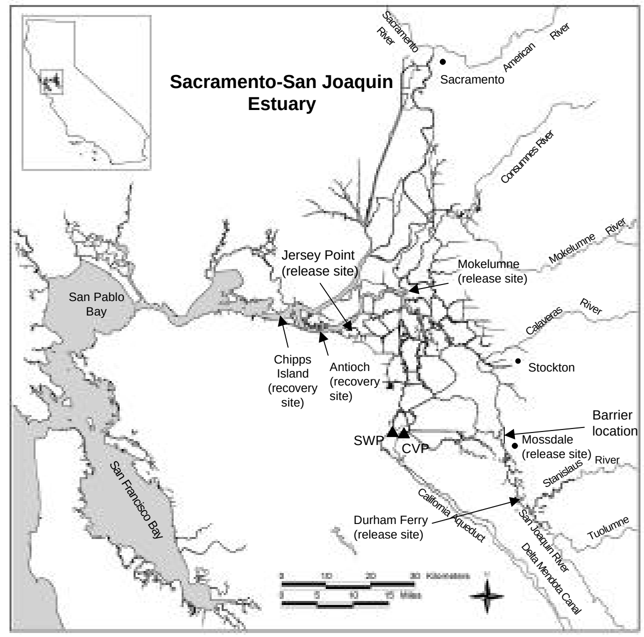

Figure 1 Location of VAMP 2000 release sites (Durham Ferry, Mossdale, Mokelumne River, and Jersey Point), recovery locations (Antioch and Chipps Island), and upper Old River barrier location within the Sacramento-San Joaquin River Delta-Estuary

Another refinement to the VAMP 2000 fisheries program involved relocating one of the recapture sites from Jersey Point further downstream to a location near Antioch. Intensive fish sampling was conducted both at the Antioch site and further downstream at Chipps Island seven days per week as part of the VAMP program from mid-April through late May. Sampling at Antioch was conducted using a Kodiak trawl, which has proven in previous studies to be effective in collecting juvenile chinook salmon. Marked salmon collected as part of these sampling programs have been frozen and will be processed later this summer and early fall to provide the information necessary to calculate survival indices for juvenile salmon released at Durham Ferry and migrating downstream through the lower San Joaquin River under the flow and export conditions established as part of the VAMP 2000 program with the head of Old River Barrier in place.

THE CHINESE MITTEN CRAB AS A POTENTIAL HOST FOR HUMAN PARASITIC LUNG FLUKES IN THE SAN FRANCISCO BAY ESTUARY

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The non-native Chinese mitten crab, *Eriocheir sinensis*, which has invaded the San Francisco Bay and associated watershed, serves as a second intermediate host for infectious parasitic lung flukes (*Paragonimus* spp.) in its native Asian habitats (Blair and others 1999; Li 1989; Yokogawa 1965; Yokogawa and others 1960). Introduction of these flukes to the U.S. could have occurred if, as some believe, mitten crabs were intentionally introduced and involved the release of infected juvenile/adult individuals.

Worldwide there are numerous species of *Paragonimus*, including 18 native to Asia and five North American species. The lifecycles of all of these species require interaction among three different types of hosts—a mammal as the final host, a freshwater snail as the first intermediate host and a freshwater crustacean (crab or crayfish) as the second intermediate host.

Adult *Paragonimus* live and produce eggs within the lungs of the mammalian host. Many different mammals occurring in the San Francisco Bay and watershed can serve as the final host for these parasites, including humans, feral and domestic cats and dogs, opossums, raccoons, foxes, and river otters. The eggs of the parasite are expelled in the saliva and/or feces of the mammal, hatch if in water, and release a swimming larval stage called a miracidium. This miracidium locates and infects an appropriate snail host. Lung flukes can use a large number of different snails as the first intermediate host (Davis and others 1994), and appropriate types of snails occur in the San Francisco Bay and watershed. Within the snail the miracidium develops into the next larval stage, the sporocyst, which, through further development and asexual reproduction gives rise to the final larval stage, the cercaria. These cercariae are responsible for infection of the crustacean host, including mitten crabs. In the crustacean, the cercariae develop into juvenile lung flukes inside of cysts known as metacercariae, which can infect humans (or other mammals) who ingest or handle raw or insufficiently cooked crab tissue.

While some question whether *Eriocheir sinensis* can function as a host for *Paragonimus* species, the relationship of *Paragonimus* with its crustacean hosts has been well studied in China and Japan. As reviewed by Blair and others (1999), *Paragonimus* species exhibit a broad degree of host specificity for their crustacean hosts. That is, a single species of lung fluke can use many different species of crustaceans as the second intermediate host. For example, the Asian species *Paragonimus westermani* can infect 50 species of crustaceans, representing 20 genera and 5 families (Blair and others 1999). Among grapsid crabs, *Eriocheir sinensis* and *E. japonicus* have both been documented as natural hosts for *P. westermani* (Blair and others 1999; Cho and others 1991; Li 1989; Lou and others 1992; Miyazaki and Chiu 1980; Yokogawa 1965; Yokogawa and others 1960).

In addition to potentially introducing a foreign parasite into the San Francisco Bay and watershed, the mitten crab may also be increasing the potential risks associated with North American species of lung flukes. These North American *Paragonimus* species also use crustaceans as intermediate hosts, including the Louisiana (red swamp) crayfish (*Procambarus clarkii*) which is present in the San Francisco Bay and watershed (Blair and others 1999). However, as lung flukes can use many different types of crustaceans, the mitten crab may also serve as a host for North American flukes. If so, “natural” levels of these parasites could substantially increase as the mitten crab is more abundant and has a wider geographic distribution and range of habitats than the crayfish, thus enhancing the potential for contact with the other hosts in the life cycle of *Paragonimus*. However, it is presently unknown whether North American or Asian lung flukes actually are, or could become, established in the San Francisco Bay and watershed population of *E. sinensis*. We have undertaken a project funded by the National Sea Grant program to answer these questions.

Until our study, the most widely cited examination of mitten crabs in the San Francisco Bay and watershed for lung flukes was a small sample of 25 individuals from one collection site. These crabs were examined at U.C. Santa Barbara, and no encysted larvae (metacercariae) of *Paragonimus* were found (Mark Torchin, personal communication, see “Notes”). However, in addition to the very small sample size and limited geographic representation of the sample, these crabs were collected and examined prior to the enormous and rapid expansion of the *E. sinensis* population in subsequent years. Further, to the best of our knowledge, crayfish and freshwater snails of the San Francisco Bay and watershed have not been examined for *Paragonimus*. We have now dissected and examined approximately 500 adult crabs from South San Francisco Bay, San Pablo Bay and the federal Tracy Fish Collection Facility. We found no metacercariae of *Paragonimus*. We are currently examining juvenile mitten crabs and the other potential hosts, crayfish and snails.

References

Blair D, Xu Z, Agatsuma T. 1999. Paragonimiasis and the genus *Paragonimus*. Advances in Parasitology 42:113–22.

Cho SY, Kang SY, Kong Y, Yang HJ. 1991. Metacercarial infections of *Paragonimus westermani* in freshwater crabs sold in markets in Seoul. Korean Journal of Parasitology 29:189–91.

Davis GM, Chen CE, Kang ZB, Lui YY. 1994. Snail hosts of *Paragonimus* in Asia and the Americas. Biomedical and Environmental Sciences 7:369–82.

Li YS. 1989. A survey of freshwater crabs harbouring parasites in Fujian Province. Acta Hydrobiologica Sinica 13:83–6.

Lou YS, Fujino T, Morita K, Ishii Y. 1992. A comparative ultrastructural and histochemical study of the metacercarial cyst walls of four species of *Paragonimus*. Parasitology Research 78:457–462.

Miyazaki I, Chiu JK. 1980. Examination of the so-called *Paragonimus westermani* in Taiwan. Medical Bulletin of the Fukuoka University 7:277–79.

Yokogawa M. 1965. *Paragonimus* and Paragonimiasis. Advances in Parasitology 3:99–158.

Yokogawa S, Cort WW, Yokogawa M. 1960. *Paragonimus* and Paragonimiasis. Experimental Parasitology 10:81–137, 139–205.

Notes

Mark Torchin. Marine Science Institute, University of California, Santa Barbara. Personal conversation with author on January 10, 1998.

Reproduction in the Chinese Mitten Crab, *Eriocheir sinensis*

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Introduction

Since the 1992 discovery of the Chinese mitten crab, *Eriocheir sinensis* (Decapoda: Brachyura) in the South San Francisco Bay, their population has expanded into the Sacramento-San Joaquin Delta system and watershed (Veldhuizen and Hieb 1998). The juvenile crabs migrate into freshwater areas where they develop into adults. In California, these crabs now range from as far north as Colusa, east to Marysville, and south to San Luis National Wildlife Refuge in Merced County (Veldhuizen and Stanish 1999). Towards the end of summer, the crabs start their seaward migration to spawn. This migration has caused much concern for the U.S. Bureau of Reclamation's Tracy Fish Recovery Facility and the Department of Water Resources Skinner Fish Recovery Facility. Issues of concern involve the loss of endangered fish species and curtailment of water pumping. During the late summer, the crab's reproductive system begins to mature. It is unknown whether the downstream migration and reproductive events are linked to a single environmental or physiological stimulus or initiated by separate stimuli.

Understanding the stimulus that initiates reproduction is critical for the development of plans that could minimize the adverse effects of the mitten crab on the estuary system, and fish and water facilities. Water temperature and day length are probable cues for stimulating reproduction in these crabs. Understanding the environmental parameters that regulate the onset of reproductive processes can provide a mechanism that will enable water managers to anticipate the onslaught of downstream migrating crabs. These data might allow monitoring water temperature and day length to predict the downstream migration of the crabs.

To initiate studies on reproduction of the mitten crab, we determined the gonadosomatic index (GSI) of downstream migrating females. These data provide a baseline against which annual comparisons can be made. To facilitate examination of reproduction, identification of a biological marker is required. Yolk, also known as vitellin, is an obvious choice for a biological marker because it composes the greatest volume of the egg. Thus, the synthesis of yolk proteins is a good indicator of female reproductive activity. (See reviews in Charniaux-Cotton 1985; Meusy and Payen 1988; Tsukimura submitted.) Furthermore, the presence of yolk proteins has been frequently used to study the environmental cues that appear to initiate reproduction.

Abbreviated Methods

Collection and Processing. From September 1999 to February 2000, downstream migrating female mitten crabs were collected at the Tracy Fish Recovery Facility and generously provided to us by S. Seigfried. Additional crabs were collected by DFG downstream of Tracy in April 2000. The live crabs were transported to CSU Fresno and maintained in recirculating aquaria at room temperature. Total body weight and ovarian weight were measured for calculation of the gonadosomatic index (GSI = [ovarian wt/body wt] x 100), an indicator of reproductive progress. Data were analyzed using one-way ANOVA (+ Tukey's Test). In addition, hemolymph samples were taken and immediately frozen at –20 °C for later use.

Protein Isolation. Vitellin (Vn) was isolated using standard techniques (Riley and Tsukimura 1998; Tsukimura and others submitted). Briefly, Vn is purified from homogenized ovaries by isolating it from cellular components through differential centrifugation. In addition, Vn is purified from the other cellular proteins with increasing concentrations of saturated ammonium sulfate solution. To determine molecular composition, Vn preparations were analyzed by (7.5% acrylamide) SDS-PAGE (Laemmli 1970) with two minor modifications: (1) not boiling the yolk preparations prior to electrophoresis and; (2) adjusting the pH of buffers above 7.4 to reduce precipitation of Vn. Proteins were fixed and stained with Coomassie stain.

Chromatography. To quantify the molecular weight, Vn was passed through a gel filtration column using the homgenization buffer as a solvent, with a flow rate of 0.25 ml/min and elution time was determined. Column elution times were equilibrated with standard molecular weight markers (Sigma #GF1000: carbonic anhydrase, 29 kDa; bovine serum albumin, 66 kDa; alcohol dehydrogenase, 150 kDa; b-amylase, 200 kDa; apoferritin, 443 kDa; thyroglobulin, 669 kDa; and blue dextran, 2,000 kDa).

Results and Discussion

From September through November, female crabs were of similar carapace width (mean = 66.3 mm; range: 59 to 78 mm carapace width) from the Tracy Fish Recovery Facility (Figure 1). The crabs in February were smaller than those in October, but not from September and November. Crabs collected in April were significantly smaller (mean carapace width = 55.1 mm) than those collected earlier. These smaller sized crabs, possessing developing ovaries and still non-ovigerous, were collected with many other ovigerous females, which may explain the size difference. These smaller crabs may take longer to reach the higher salinity waters that are required for final ovarian maturation. The crabs from Tracy BOR were similar in size to downstream migrating mitten crabs reported in France (42 to 74 mm) (Hoestlandt 1948), but larger than those reported for fourth- and fifth-year crabs (38 to 50 mm) in other regions of Europe (Ingle 1986).

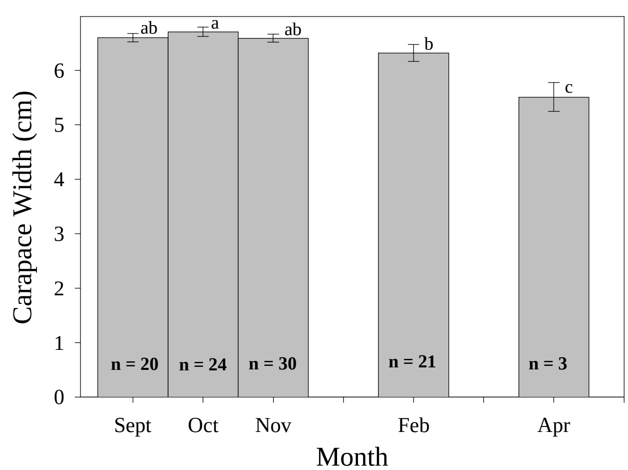

Figure 1 Mean carapace width for female *Eriocheir sinensis* collected at the Tracy Fish Recovery Facility. Fall sizes are similar, whereas differences occur in later months. The smaller females may require more time to descend from their freshwater habitats. Data were analyzed using one-way ANOVA (+ Tukey's Test). Means followed by the same letter are not significantly different ($p < 0.05$). "*n*" indicates number of individuals examined. Note that April animals were collected downstream of Tracy and were significantly smaller than earlier months. These crabs were not yet ovigerous, but were collected when many larger crabs were already ovigerous.

Female mitten crabs migrating downstream in September had lower GSI (4.5%) than all female crabs in successive months (7.8%), except for April (Figure 2). Because the carapace sizes of these crabs are similar, the smaller GSI appears to reflect these crabs' earlier reproductive development in comparison to crabs collected in later months. Only three non-ovigerous females were collected in April with a wide range of GSI data (3.6% to 12.8%). Data from France indicate that developing oocytes are common in downstream migrating mitten crabs (Hoestlandt 1948). The completion of ovarian development occurs in brackish water (DeLeersnyder 1967), thus it would not be expected that animals with significantly larger GSI would be found at Tracy.

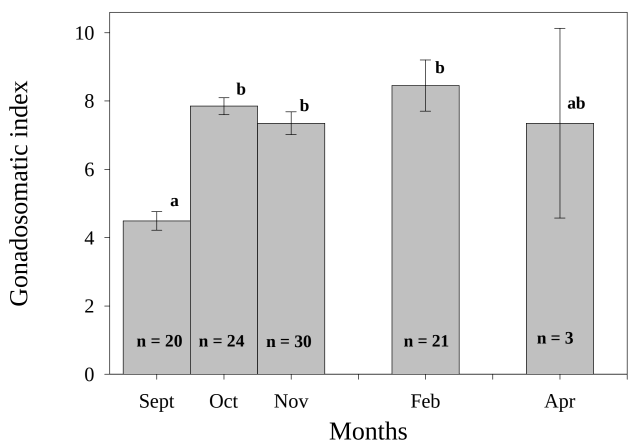

Figure 2 Mean GSI for female *Eriocheir sinensis* collected at the Tracy Fish Recovery Facility. Females caught in September had significantly lower GSI than the successive months. Data were analyzed using one-way ANOVA (+ Tukey's Test). Means followed by the same letter are not significantly different ($p < 0.05$). "*n*" indicates number of individuals examined.

Upon purification of the Vn, the protein was analyzed by HPLC column chromatography and determined to be 618 kDa in molecular mass. This size is large compared to the known molecular mass for other crabs (Tsukimura submitted). For example, the Vn of the green crab, *Carcinus maenas*, has a molecular mass of 480 kDa (Andrieux and deFrescheville 1992), and *Potamon potamias* Vn has a molecular mass of 551 kDa (Pateraki and Stratakis 1997). Under denaturing conditions, *E. sinensis* Vn consists of four subunits (111 kDa, 112 kDa, 127 kDa and 135 kDa) (Figure 3). In other crabs, Vn is composed of two to four subunits (with molecular mass ranging from 39 to 188 kDa) (Tsukimura submitted). *Eriocheir japonica* has two subunits (Komatsu and Ando, 1992). Other crabs with two Vn subunits are: the green crab, *Carcinus maenas*, (Andrieux and de Frescheville 1992); *Uca pugilator* (Eastmen-Reks and Fingerman 1985); and *Charybdis feriata* (Komatsu and Ando 1992). In addition, the rock crab, *Cancer antennarius*, has three subunits (Lee and Puppione 1988; Spaziani 1988) and the blue crab, *Callinectes sapidus*, has four subunits (Lee and Watson 1995).

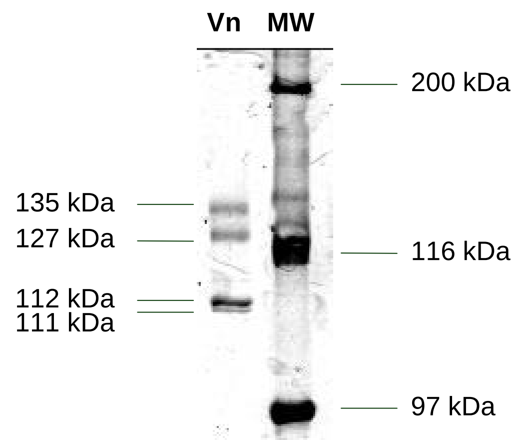

Figure 3 SDS-PAGE separation of *Eriocheir sinensis* vitellin (Vn) demonstrating the presence of four subunits, with sizes indicated. Molecular mass (MW) markers are shown on the right side.

We have developed and characterized an anti-Vn antiserum. Thus far we have found that the antisera only bind the four subunits of Vn when examining crude ovarian extracts and reproductive female hemolymph (data not shown). This makes it useful for the identification of yolk protein molecules from hemolymph samples. We are currently using this anti-Vn antiserum to develop an Enzyme-linked Immunosorbant Assay (ELISA) with which hemolymph levels of yolk proteins can be determined. We have previously collected hemolymph samples from mitten crabs last fall and winter that will be assayed for yolk protein levels. These data will then be compared to the GSI and carapace data to better assess the amount of ovarian development that is occurring in downstream migrating female mitten crabs.

During oocyte development, yolk proteins are synthesized both within the oocyte and often in the hepatopancreas, which is the crustacean equivalent to the liver (see review in Tsukimura submitted). The yolk is transported through the hemolymph to the oocytes where it is incorporated into the egg (Charniaux-Cotton 1985). Thus, the amount of yolk protein in the hemolymph is an indicator of reproductive progress, and at least, an indicator of gonadal development.

In summary, we have established a baseline GSI and size of downstream migrating female crabs at the Tracy Fish Recovery Facility. These data will be used to compare carapace sizes and GSI for fall 2000–winter 2001 crabs. In addition, we have purified and characterized the yolk protein of the mitten crab, then developed an anti-Vn antiserum. We will use this antiserum in an ELISA that will detect changes in yolk protein levels in hemolymph. This assay will be useful in examining environmental and physiological cues that stimulate ovarian development.

At the last annual meeting of the Society for Integrative and Comparative Biology where a crustacean physiology symposium was convened, much interest was generated about the presence of the Chinese mitten crab invasion of California. This is the only catadromous crab in North America. Many biologists were interested in the crab's physiological abilities to withstand salinity and temperature changes, as well as how the crab regulates molts and tissue growth. Although the full impact of this invasive species remains unknown, it is a useful organism to study basic crustacean biology.

REFERENCES

Anderson SL, Clark WH, Chang ES. 1985. Multiple spawning and molt synchrony in a free spawning shrimp (*Sicyonia ingentis*: Penaeoidea). Biol Bull 168:377–94.

Andrieux and deFrescheville. 1992. *Caratérization de la vitelline secondaire chez le Crustacé Brachyoure* Carcinus maenas. CR Acad Sci Paris Ser III 314:227–30.

Charniaux-Cotton H. 1985. Vitellogenesis and its control in malacostracan crustacea. Am Zool 25(1):197–206.

De Leersnyder M. 1967. *Influence de la salinité et l'ablation des pédoncles oculaires sur la mue et sur le développement ovarien d'*Eriocheir sinensis H. Milne-Edwards. Cah Biol Mar 8:421–35.

Eastman-Reks SB, Fingerman M. 1985. In vitro synthesis of vitellin by the ovary of the fiddler crab *Uca pugilator*. J Exp Zool 233:111–6.

Hoestlandt H. 1948. *Recherches sur la biologie de l'*Eriocheir sinensis H. Milne-Edwards (*Crustacé Brachyoure*). Ann Inst Océanogr 24:1–116.

Ingle RW. 1986. The Chinese mitten crab *Eriocheir sinensis* H. Milne-Edwards—a contentious immigrant. Lond Naturalist 65:101–5.

Komatsu M, Ando S. 1992. Isolation of crustacean egg yolk lipoproteins by differential density gradient ultracentrifugation. Comp Biochem Physiol 103B:363–8.

Laemmli UK. 1970. Cleavage of structural proteins during the assembly of bacteriophage T4. Nature (London) 227:680–5.

Lee C-Y, Watson RD. 1995. In vitro study of vitellogenesis in the blue crab (*Callinectes sapidus*): Site and control of vitellin synthesis. J Exp Zool 271:364–72.

Lee RF, Puppione DL. 1988. Lipoproteins I and II from the hemolymph of the blue crab *Callinectes sapidus*: Lipoprotein II associated with vitellogenesis. J Exp Zool 248:278–89.

Meusy JJ, Payen GG. 1988. Female reproduction in malacostracan Crustacea. Zool Sci 5:217–65.

Pateraki LE, Stratakis E. 1997. Characterization of vitellogenin and vitellin from the land crab *Potamon potamios*: Identification of a precursor polypeptide in the molecule. J Exp Zool 279:597–608.

Riley LG, Tsukimura B. 1998. Yolk protein synthesis in the riceland tadpole shrimp, *Triops longicaudatus*, measured by in vitro incorporation of 3H-Leucine. J Exp Zool 182:238–47.

Spaziani E. 1988. Serum high density lipoprotein in the crab, *Cancer antennarius* Stimpson: II. Annual cycles. J Exp Zool 246:315–8.

Tsukimura B, Bender JS, Linder CJ. Developmental aspects of gonadal regulation in the ridgeback shrimp, *Sicyonia ingentis*. Submitted.

Tsukimura B. Crustacean vitellogenesis: Its role in oocyte development. American Zoologist. Submitted.

Veldhuizen T, Hieb K. 1998. What's new on the mitten crab front? IEP Newsletter 12(2):24–5.

Veldhuizen T, Stanish S. 1999. Overview of the life history, distribution, abundance, and impacts on the Chinese mitten crab, *Eriocheir sinensis*. Report prepared for the U.S. Fish and Wildlife Service. Sacramento (CA): California Department of Water Resources. 26 p.

SPECIFIC CONDUCTANCE, WATER TEMPERATURE, AND WATER LEVEL DATA FROM SAN FRANCISCO BAY, CALIFORNIA, IN WATER YEAR 1999

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INTRODUCTION

This article presents time-series plots of specific-conductance, water-temperature, and water-level data collected at seven sites in San Francisco Bay during water year 1999 (October 1, 1998 through September 30, 1999). Specific conductance and water temperature data are recorded continuously at the following locations (Figure 1).

- Carquinez Strait at Carquinez Bridge
- Napa River at Mare Island Causeway near Vallejo
- San Pablo Bay at Petaluma River Channel Marker 9
- San Pablo Strait at Point San Pablo
- Central San Francisco Bay at Presidio Military Reservation
- Central San Francisco Bay at Pier 24
- South San Francisco Bay at San Mateo Bridge near Foster City

Water level data are recorded only at Point San Pablo. The data from Point San Pablo, Presidio, Pier 24, and San Mateo Bridge were recorded by the California Department of Water Resources (DWR) before 1988, by the U.S. Geological Survey (USGS) National Research Program from 1988 to 1989, and by the USGS-DWR cooperative program since 1990. The Carquinez Bridge, Napa River, and San Pablo Bay sites were established in 1998 by the USGS.

DATA COLLECTION

Typically, specific conductance and water temperature data were collected at near-surface and near-bottom depths in the water column to define the vertical stratification. However, at the more shallow San Pablo Bay and Presidio sites, data were collected only at near-bottom depth because the mean lower-low water depth was about six feet. The mean lower-low water depth is the average of the lower-low water height of each tidal day observed during the National Tidal Datum Epoch [the specific 19-year period (1960–1978) adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values]. The San Mateo Bridge site was shut down in March 1999 for seismic retrofitting of the bridge and data collection is scheduled to resume in June 2000.

Figure 1 Location of specific conductance, water temperature and water level data continuous monitoring sites in San Francisco Bay, California

Specific conductance (reported at 25 °C) was measured using either a Foxboro electrochemical analyzer (calibrated accuracy ± 3%) or a Hydrolab Datasonde 4 multiprobe (conductivity cell calibrated accuracy ± 1%). Water temperature was measured using a Campbell Scientific thermister (accuracy ± 0.4°C) or the Hydrolab Datasonde 4 multiprobe (temperature probe accuracy ± 0.1°C). Water level was measured using a Handar incremental encoder with a float-driven, incremental, stainless steel tape. Specific conductance, water temperature, and water level measurements were made and data were stored every 15 minutes, controlled by a Campbell Scientific CR10 data logger or the Hydrolab Datasonde 4 multiprobe internal data logger.

Instrument calibrations were completed in the field every two to three weeks. Calibration of the continuous recording instruments measuring specific conductance was done using an Orion model 140 conductivity meter (calibrated accuracy ± 2%) calibrated to a known specific conductance standard. Calibration of the water temperature instruments was done using a VWR Scientific thermister (accuracy ± 0.2 °C). Water level instruments were checked using a wire-weight gage mounted to the pier at Point San Pablo. Data corrections (normally resulting from biological fouling), based on differences between the continuous-recording instrument readings and the field-calibrated instrument readings, were applied to the record for final computation using the USGS Automated Data Processing System.

Data Presentation

Figures 2 through 6 show time-series plots of the specific conductance, water temperature, and water-level data measured at the seven sites in San Francisco Bay. Tidal variability (ebb and flood) affects specific conductance, water temperature, and water level. In Figures 2 through 6, the degree of tidal variability corresponds with the vertical range of the "black bands," which is caused by compressing a year of time-series data into a small plot. To illustrate tidal variability, Figure 7 shows the near-surface and near-bottom specific conductance and water level at Point San Pablo for the 24 hours of December 25, 1998. Tidal variability was greater in San Pablo Bay than in South San Francisco Bay (Schoellhamer 1997). Gaps in the data usually are caused by equipment malfunctions.

Maximum and minimum values of specific conductance, water temperature, and water level data for the seven sites are published annually in volume 2 of the USGS California water data report series, which is available on the USGS website at http://water.wr.usgs.gov.

Figure 2 Near-surface (NS) and near-bottom (NB) measurements of specific conductance at Carquinez Bridge (CARQ), Napa River (NAP), Point San Pablo (PSP), and San Pablo Bay (SPB), San Francisco Bay, water year 1999. For reference, seawater has a specific conductance of 53,000 microSiemens per centimeter.

Figure 3 Near-surface (NS) and near-bottom (NB) measurements of specific conductance at San Mateo Bridge (SMB), Pier 24 (P24), and Presidio (PRES), San Francisco Bay, water year 1999. For reference, seawater has a specific conductance of 53,000 microSiemens per centimeter.

Figure 4 Near-surface (NS) and near-bottom (NB) measurements of water temperature at Carquinez Bridge (CARQ), Napa River (NAP), Point San Pablo (PSP) and San Pablo Bay (SPB), San Francisco Bay, water year 1999

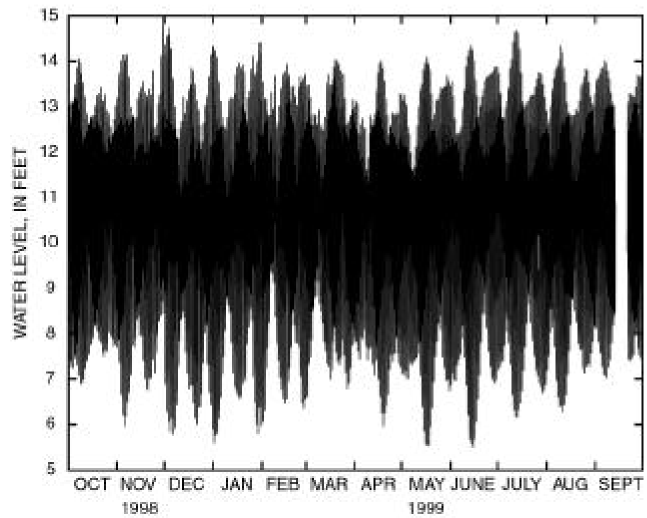

Figure 6 Water levels at Point San Pablo, San Francisco Bay, water year 1999. Vertical datum is 10 ft below sea level.

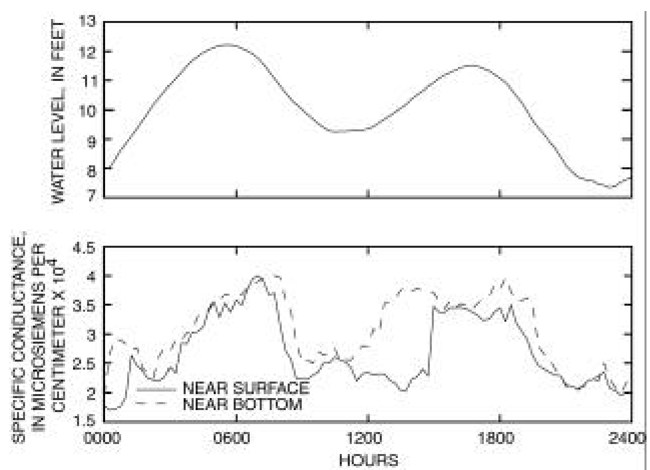

Figure 7 Near-surface and near-bottom measurements of specific conductance and water levels at Point San Pablo, San Francisco Bay on December 25, 1998. Vertical datum is 10 ft below sea level. For reference, seawater has a specific conductance of 53,000 μS/cm.

Figure 5 Near-surface (NS) and near-bottom (NB) measurements of water temperature at San Mateo Bridge (SMB), Pier 24 (P24), and Presidio (PRES), San Francisco Bay, water year 1999

REFERENCES

Schoellhamer DH. 1997. Time series of SSC, salinity, temperature, and total mercury concentration in San Francisco Bay during water year 1996: 1996 Annual Report of the Regional Monitoring Program for Trace Substances. p 65–77.

CONTRIBUTED PAPERS

PRIMARY FOOD RESOURCES IN THE SACRAMENTO-SAN JOAQUIN DELTA

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INTRODUCTION

The Sacramento-San Joaquin River Delta, a complex mosaic of tidal freshwater habitats, is now a focus of ecosystem rehabilitation because of changes in critical functions associated with its geographic location at the land-estuary interface. One of these functions is the production, transport, and transformation of organic matter that constitutes the "primary food supply," that is, the food supply to the base of the food web. Interest in the primary food supply is motivated by evidence for sub-optimal food quantity or quality at trophic levels that support fish recruitment, including primary consumers such as clams, mysids, cladocerans, rotifers, and native copepods. We used the historical data set to examine the magnitudes of the most important organic matter sources for the Delta, the factors underlying their interannual and longer-term variability, and the implications of ecosystem rehabilitation actions for these sources. Here, we present a summary of the first phase of the analysis, including the quantitative importance of different organic matter sources and some of the hydrological controls on their year-to-year variability. The full report of this first phase-including data sources, the methods of calculation, and references, is in press elsewhere (Jassby and Cloern forthcoming). The historical data analysis is part of a larger project in which measurements of stable isotopes and biogeochemical markers, and experiments on organic matter biodegradation and zooplankton growth rates, are being used collectively to define the primary food resources and their quality.

GROSS ORGANIC MATTER SOURCES

Organic matter sources in terms of total organic carbon (TOC) are summarized in Table 1. Comparisons are possible only on an average annual Delta-wide basis for most of these sources. Tributary-borne loading is the largest source overall. Phytoplankton production (estimated from a model that incorporates incident light, phytoplankton biomass, and water clarity) and agricultural drainage are secondary sources. Wastewater treatment plant discharge, marsh export, and possibly aquatic macrophyte production are tertiary sources. Benthic microalgal production, urban runoff and other sources not explicitly mentioned are negligible. Phytoplankton is clearly the dominant primary producer on a Delta-wide basis, whereas tributary-borne loading is dominant among the allochthonous (external) sources. The ratio of combined primary production to total sources is only 15%. It is important to note that these are sources for benthic habitat and water column combined. An accounting for the water column alone would have to isolate the supply of dissolved organic carbon (DOC) from the sediments. DOC can be a significant source for bacterioplankton production.

For most of the organic matter supply, sufficient data exist to compare based on season and water year classification. A water year extends from October 1 of the previous calendar year to September 30. Water years in the Sacramento River Basin are classified based on annual stream flow data into (1) wet, (2) above-normal, (3) below-normal, (4) dry, and (5) critical. We combined (1) and (2) into a category referred to as "above normal" and (3) to (5) into a category referred to as "below normal." For each category, we compared phytoplankton productivity and tributary-borne load, only for those years in which complete data are available for each of these sources. Agricultural drainage is also included, although we have had to assume that the amount is independent of year (Table 2).

Table 1 Annual average organic carbon sources for the Delta[a]

	TOC (T/d)
Primary producers	
Phytoplankton gross primary production	47 ± 5 (*n* = 9)
Macrophytes	<12
Benthic microalgae	0.38
Allochthonous sources	
Tributary-borne load	270 ± 50 (*n* = 16)
Agricultural drainage	36
Tidal marsh export	14
Wastewater discharge	12
Urban runoff	2.2

[a] Phytoplankton gross primary production and tributary-borne riverine load (± standard error of the mean) are for the *n* years in which necessary data are available every month. All values are rounded to two significant digits.

Table 2 Major organic carbon sources for the Delta (T/d C ± standard error of the mean among years) based on season and water year type (1968–1995)[a]

	Phytoplankton GPP	Tributary load	Agricultural drainage	No. of years
Above normal				
Autumn	26 ± 7	140 ± 40	23	3
Winter	5.7 ± 2.0	1300 ± 290	70	4
Spring	75 ± 21	310 ± 50	27	5
Summer	69 ± 4	200 ± 19	26	7
Below normal				
Autumn	19 ± 3	150 ± 32	23	7
Winter	22 ± 7	230 ± 39	70	7
Spring	100 ± 13	120 ± 8	27	10
Summer	62 ± 6	130 ± 14	26	10

[a] The number of years for which data are available to compare phytoplankton and tributary contributions is also shown. Data are not sufficient to describe agricultural drainage contributions based on water year type. Two significant digits are shown.

Phytoplankton production, tributary-borne loading and agricultural drainage together account for 90% of total sources. In above normal years, tributary-borne loading is always dominant. Although phytoplankton productivity is small compared to agricultural drainage in winter, it is similar in autumn and much greater during spring and summer. A comparison among water year types shows, phytoplankton productivity increases in spring of below-normal years because of higher hydraulic residence time and the resulting accumulation of phytoplankton biomass. Tributary-borne loading, in contrast, decreases in below-normal years because of lower inflows. Consequently, the two sources are similar in magnitude. Even in summer of below-normal years, they differ by only a factor of two. The relative importance of sources is therefore clearly dependent on season and on the prevailing climate conditions.

Many of these sources are also distributed in a spatially heterogeneous manner. This diversity and heterogeneity implies that the relative importance of sources will change as we move from one Delta subregion to another. The aquatic vascular plant *Egeria densa*, for example, covered 35% of Franks Tract in September 1997. If we assume this level of coverage for the year and apply our phytoplankton productivity estimates from one station in Franks Tract to the remaining area, then annual *Egeria* and phytoplankton production are within 10% of each other. Similarly, much of the remaining tidal marsh habitat in the Delta is found in the western portion, and so tidal marsh export is bound to be more important in this region. In the San Joaquin River near Vernalis, large phytoplankton blooms occur, sometimes reaching chlorophyll *a* concentrations of over 50 µg/L. Phytoplankton production is most likely the dominant organic matter source in this part of the Delta during spring and summer.

NET ORGANIC MATTER SOURCES

These sources differ in their availability to the food web, and a further refinement is necessary before they can be directly compared as food sources. Particulate organic carbon (POC) enters the Delta from allochthonous sources mostly as phytoplankton and phytoplankton-derived detritus, other microscopic detrital particles, microheterotrophs, and suspended mineral particles with adsorbed organic matter. It is not clear how much the latter form of POC participates in the food web. The remaining POC input immediately becomes part of the microscopic particle or microalgae pool; it should be just as available to the metazoan food web as particulate primary production. In contrast, allochthonous dissolved organic carbon (DOC) must go through an additional step before it becomes available to the metazoan food web (Figure 1). Conversion to POC does not guarantee incorporation into the metazoan food web, but at least it places DOC input on a par with microscopic food particles. It is essential to consider the losses during this step, because most of the allochthonous organic matter enters in dissolved form. In a similar vein, we must also correct gross primary productivity for losses due to phytoplankton respiration. Then we can more accurately compare allochthonous sources and primary production in terms of net food particle production. These corrections, detailed in the full manuscript, take into account (1) the proportion of DOC that is labile; (2) bacterial growth efficiency; (3) the ratio of DOC:TOC; and (4) a simple model for phytoplankton respiration that includes basal metabolism and photosynthesis-dependent losses.

When these losses are taken into account, the relative importance of organic matter sources changes dramatically (Table 3). Except for above-normal winters, net phytoplankton productivity is a significant source in all seasons. Moreover, phytoplankton productivity is comparable to and sometimes greater than tributary-borne loading in spring and summer of both above-normal and below-normal water years. Spring and summer are particularly critical seasons for larval development and recruitment success. In contrast, agricultural drainage is almost never significant.

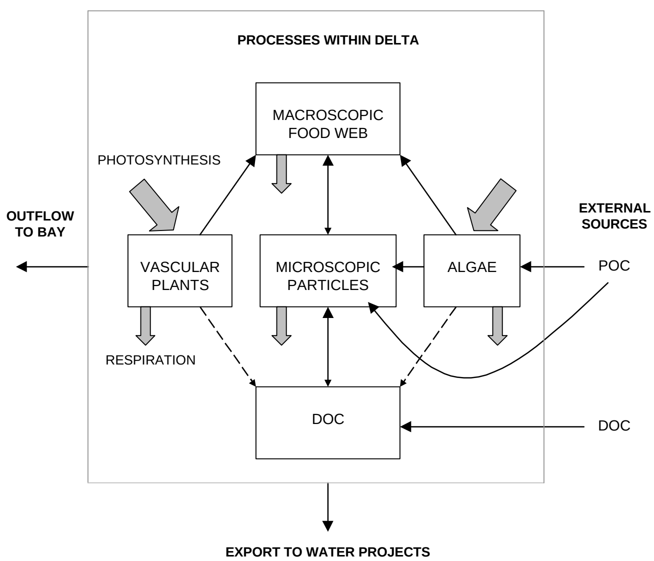

Figure 1 A simplified model of organic carbon pools and flows in the Sacramento-San Joaquin Delta. The thick gray arrows represent exchange with the CO_2 pool through photosynthesis or respiration. The dashed arrows represent flows of secondary significance.

Table 3 "Net" organic carbon sources for the Delta's food web (T/d C)[a]

	Phytoplankton NPP	*Tributary load*	*Agricultural drainage*
Above normal			
Autumn	20	51	3.3
Winter	3.9	460	10
Spring	58	110	3.9
Summer	54	74	3.8
Below normal			
Autumn	14	53	3.3
Winter	17	82	10
Spring	81	44	3.9
Summer	50	48	3.8

[a] Results expressed similar to Table 2, except (1) phytoplankton NPP (net primary productivity) has been corrected for respiration, and (2) tributary load and agricultural drainage have been corrected for refractory DOC and losses of labile DOC during conversion to heterotroph biomass.

Role of Allochthonous POC

The above considerations imply that tributary-borne DOC contributes little to the available supply. From the viewpoint of primary food sources, the main function of the tributaries is to deliver POC. What is the value of this allochthonous POC as food for primary consumers? Although we cannot characterize this POC completely, at times a large fraction appears to be phytoplankton and phytoplankton-derived detritus (Figure 2). Moreover, the supply of this river-borne phytoplankton material can sometimes compare with production within the Delta (Figure 3). Some of the remaining portion of the POC load is composed of nonliving organic detritus along with bacteria and other heterotrophs. Generally, the food value of detritus and bacteria is not as high as phytoplankton, and it is enhanced when supplied in combination with phytoplankton, which contains higher amounts of essential fatty acids and other substances. Phytoplankton-derived material is therefore important beyond its simple contribution to the total POC loading. A final portion of the POC load is organic matter adsorbed to mineral suspensoids. Clay-organic-bacteria aggregates can be important components of turbid systems. The concentration of POC on clay increases bacterial growth efficiency and the use of these aggregates directly by larger zooplankton bypasses the inefficient microzooplankton link of nanoflagellates and ciliates. While a large portion of the load may be in this form at times, its value for the food web remains unknown and it remains a major gap in our understanding of organic matter supply.

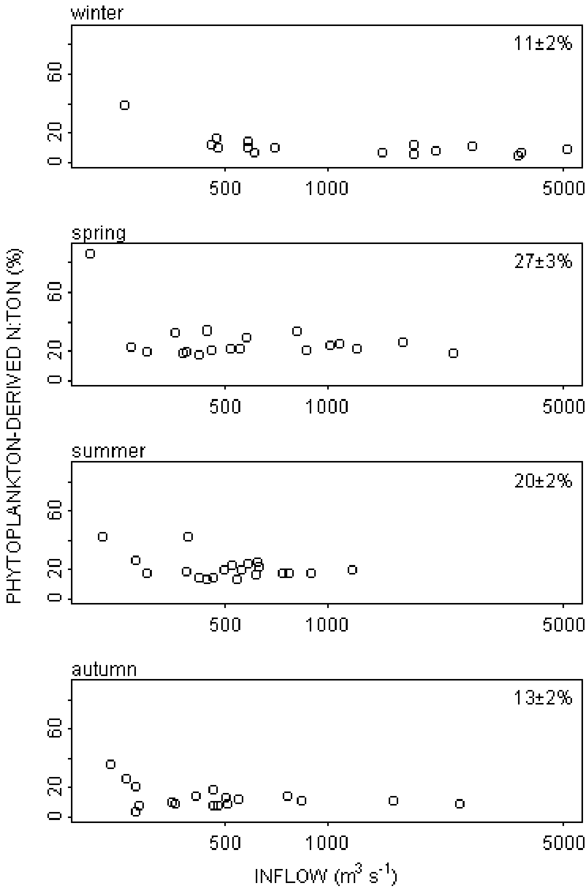

Figure 2 Phytoplankton-derived PON as a percentage of total organic N (TON) loading into the Delta, as a function of season and river flow. Note that the phytoplankton percentage of PON loading into the Delta must be even higher. Inset values: seasonal means (± standard error of the mean among years).

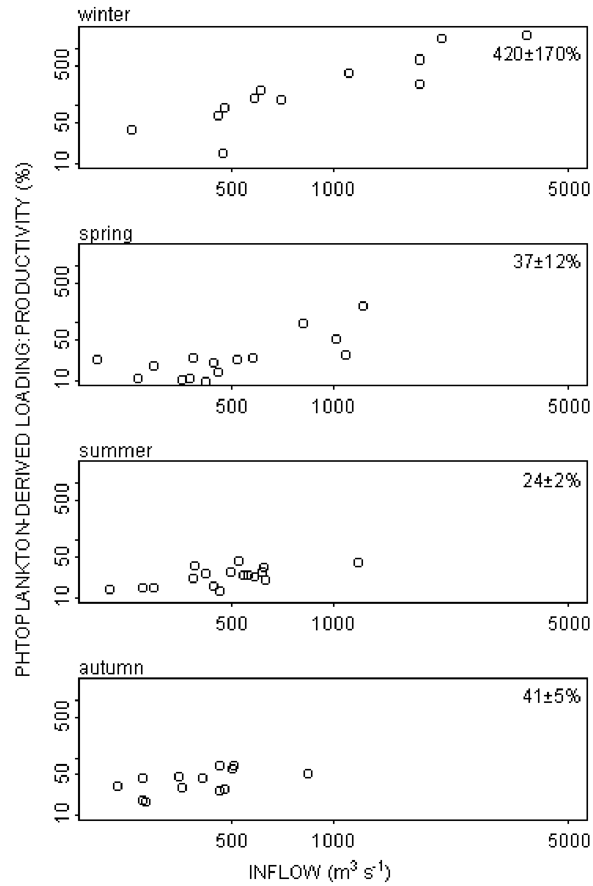

Figure 3 Phytoplankton-derived POC loading into the Delta relative to phytoplankton productivity within the Delta, as a function of season and river inflow. Inset values: seasonal means (± standard error of the mean among years).

THE DELTA AS A TRANSITION ZONE

Suisun Bay and the western Delta downstream of our boundary at Rio Vista–Twitchell is the site of an important larval fish nursery. The estuarine turbidity maximum with its unique biological characteristics and elevated POC is found in this downstream region. The Delta can be viewed as a kind of transformer, either attenuating or enhancing the mass loading from tributaries before discharging into this region and ultimately San Francisco Bay. What net effect does the Delta have on delivery of this material? We examine this question by comparing mass loading ratios for total organic nitrogen (TON) in wet versus critically dry water years. The wet and critically dry years were chosen for comparison because they are the extreme categories and because the necessary data are available.

Table 4 demonstrates that, on the upstream side, the Sacramento River contributed most TON loading. Nonetheless, the San Joaquin River contributed 20% to 42% of the total on a seasonal basis, much higher than expected based on flow. The main difference of note between year types is the proportion flowing downstream—that is, the outflow:efflux ratio—in wet versus critical years. In critical years, the proportion of the efflux flowing out into the ecologically important area just downstream of the Delta drops by almost half. Only 24% to 47% of the TON, depending on the season, flows downstream into the Bay; the remaining 53% to 76% is exported from the Bay-Delta for use elsewhere.

Table 4 Mass loading ratios (± standard error of the mean among years) for TON in wet and critically dry years, for water years in which necessary data are available every month[a]

Mass loading ratios	*Autumn*	*Winter*	*Spring*	*Summer*
Wet years[b]				
Sacramento:total influx	0.56 ± 0.04	0.57 ± 0.04	0.41 ± 0.03	0.55 ± 0.04
San Joaquin:total influx	0.30 ± 0.04	0.20 ± 0.04	0.42 ± 0.04	0.37 ± 0.03
efflux:influx	0.88 ± 0.19	1.14 ± 0.21	0.97 ± 0.08	1.03 ± 0.08
outflow:efflux	0.60 ± 0.10	0.88 ± 0.03	0.68 ± 0.12	0.36 ± 0.07
Critically dry years[c]				
Sacramento:total influx	0.70 ± 0.05	0.73 ± 0.02	0.66 ± 0.05	0.73 ± 0.04
San Joaquin:total influx	0.27 ± 0.05	0.22 ± 0.02	0.29±0.04	0.25 ± 0.04
efflux:influx	1.20 ± 0.14	1.18 ± 0.11	1.11 ± 0.05	0.85 ± 0.07
outflow:efflux	0.34 ± 0.05	0.47 ± 0.06	0.35 ± 0.03	0.24 ± 0.06

[a] Influx = sum of all river inputs; outflow = loading into Bay; efflux = loading into Bay plus exports to the water projects.
[b] 1978, 1982, 1984, 1986.
[c] 1976–1977, 1987–1988, 1990–1991.

Several points implied by the data of Table 4 require emphasis because of their ecological and management importance to Suisun Bay and the rest of San Francisco Bay downstream. First, the Delta can act as a net producer rather than net consumer of organic matter in critical years. Second, whether or not the Delta augments the supply of inflowing organic matter, enough is exported from the system so that organic matter outflow into the Bay is much less than inflow from tributaries to the Delta. Finally, even with losses to exports, organic matter loading from the Delta to Suisun Bay is still significant compared to sources within the Bay. For example, we previously estimated organic matter sources in Suisun Bay to be 3.9 T/d TON, exclusive of riverine loading. In the present study, we estimate the mean (± standard error of the mean) for riverine loading to Suisun Bay, i.e., outflow from the Delta, to be 17 ± 4 T/d TON. Taken together, these points demonstrate that flow management has profound effects on the supply of organic matter to Suisun Bay and, therefore, the food supply for larval fish in this important nursery area.

CONCLUDING REMARKS

In general, the results demonstrate that the phytoplankton-derived organic matter supply, both from production within the Delta as well as from upstream loading, is much more important for food particle production than apparent from a simple accounting of organic carbon. Its importance is probably even greater than indicated by our quantitative analysis, for two reasons. First, even though DOC may be converted to bacterial biomass, the bacteria must be repackaged as larger particles before being consumed by many mesozooplankton. This may happen automatically if the bacteria are part of a clay-organic-bacteria aggregate, but otherwise requires consumption of bacteria by microzooplankton with attendant losses due to respiration. Second, recent research suggests primary consumers such as zooplankton may be limited by the availability of certain polyunsaturated fatty acids found in phytoplankton, not by energy or generic organic carbon. Insofar as this is true, bacteria and perhaps even the non-phytoplankton-derived organic carbon from upstream may be a relatively poor food source. In any case, as demonstrated in the full paper, restoration actions—including new canals, flow and fish barriers, increased use of floodplains, and increased shallow-water habitat—all have significant effects on phytoplankton production, some positive and some negative. Given the significance of phytoplankton production to the food base in the Delta, these effects must be defined quantitatively and used to help guide the restoration strategy.

ACKNOWLEDGMENTS

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REFERENCES

Jassby AD, Cloern JE. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and Freshwater Ecosystems. Forthcoming.

Floodplain Rearing May Enhance Growth and Survival of Juvenile Chinook Salmon in the Sacramento River

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Although the trophic dynamics of large rivers are strongly affected by upstream inputs (Vannote and others 1980), there is increasing recognition that floodplain habitat plays a major role in the productivity and diversity of riverine communities (Junk and others 1989). Here we provide evidence that floodplain provides better habitat than adjacent river channels for juvenile chinook salmon (*Onchorhynchus tshawytscha*) in the Sacramento River. The system is particularly well-suited to a comparative study because young salmon migrating down the lower Sacramento River (Figure 1) in high flow years have two alternative paths: they may continue down the heavily-channelized main river or they may pass through the Yolo Bypass, the primary floodplain of the estuary. The 24,000 ha floodplain seasonally floods in winter and spring in about 60 percent of water years, when it is designed to convey up to 14,000 m^3/s. Under typical flood events, water spills into Yolo Bypass via Fremont Weir (Figure 2) when Sacramento basin flows surpass approximately 2,000 m^3/s.

We had several reasons to believe that floodplain habitat might be important habitat for young salmon. First, high flow years are known to enhance populations of a variety of estuarine species (Jassby and others 1995) and survival of young chinook salmon (Kjelsen and others 1982; Brandes and McLain forthcoming). However, the exact mechanisms for high flow years enhance populations of salmon and other species have not been established. Floodplain inundation is one of the unique characteristics of wet years, when the Yolo Bypass is likely to be a significant migration corridor for young Sacramento Valley salmon. During high flow events the Yolo Bypass can convey 75 percent or more of the total flow from the Sacramento River basin, the major producer of salmon in the system. Second, we had evidence that floodplain inundation provides major habitat for another migratory estuarine fish, the Sacramento splittail (*Pogonichthys macrolepidotus*) (Sommer and others 1997).

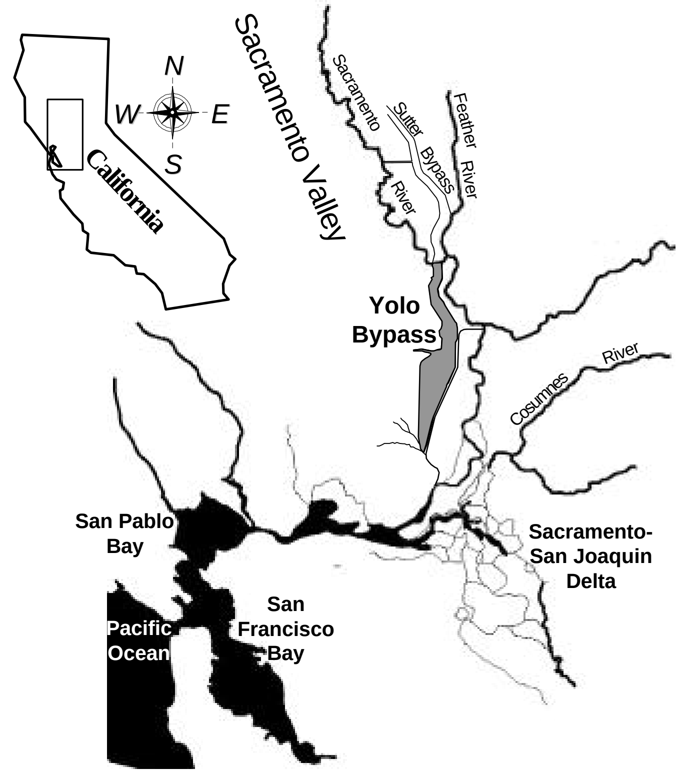

Figure 1 Location of Yolo Bypass in relation to the San Francisco Estuary and its tributaries

Materials and Methods

During 1998 and 1999 we studied the Yolo Bypass and the adjacent Sacramento River. Flow data were taken from U.S. Geological Survey gauges. Daily water temperatures for each site were calculated for single stations in the Sacramento River (USGS) and a data logger (Onset Corp) installed at the base of the Yolo Bypass (Figure 2).

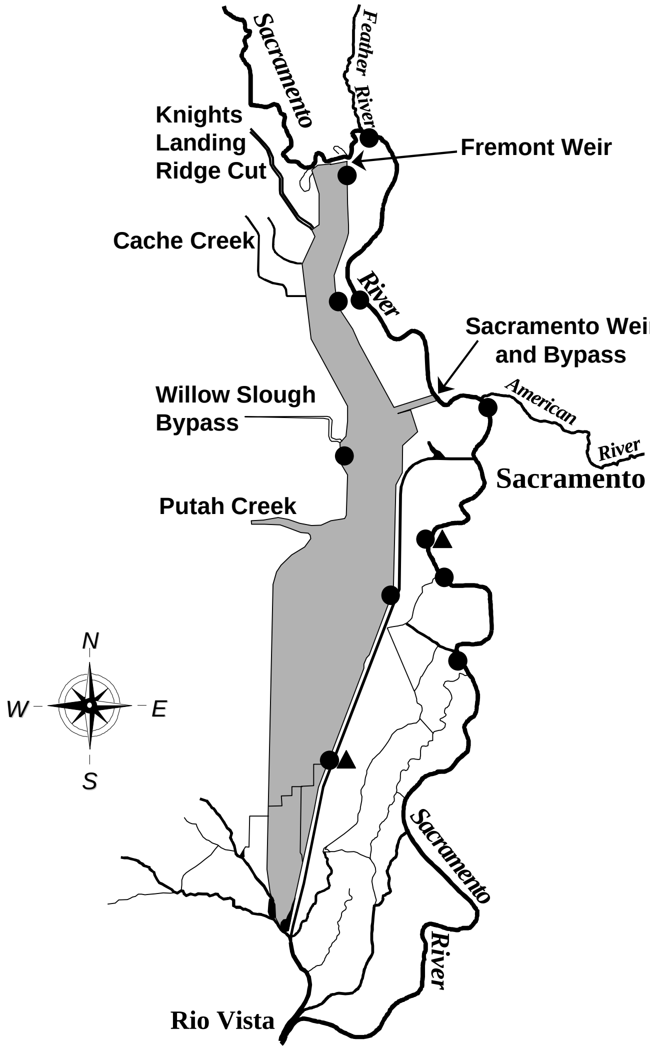

Figure 2 Sacramento River, Yolo Bypass, and its primary tributaries. Sampling locations are shown for beach seine (circles) and water temperature (triangles).

Salmon fork length (mm) was measured from January through April in 1998 and 1999 from fish samples collected by 15-m beach seines. When the bypass was flooded, samples were collected weekly at five core locations (Figure 2) located around its perimeter. As the bypass was draining, additional samples were collected at semi-randomly selected ponds near the five core locations. Comparative data on salmon size in the adjacent reach of the Sacramento River were collected by USFWS at six stations using techniques similar to those used in the bypass. Additional information on salmon growth was collected using paired releases of coded-wire-tagged (CWT) salmon fry in the Yolo Bypass and Sacramento River. This approach allowed growth comparisons on fish of a similar origin and provided a relative estimate of migration time and survival. The salmon fry were produced and tagged at the Feather River Fish Hatchery and released on March 2, 1998 and February 11, 1999. The release sites were in Yolo Bypass below Fremont Weir (52,000 in 1998; 105,000 in 1999) and in the adjacent reach of the Sacramento River (53,000 in 1998; 105,000 in 1999). Each release group had a mean fork length of approximately 57 mm. Migration time and lengths of CWT salmon released in the Sacramento River and the Yolo Bypass were compared for fish recaptured at Chipps Island in the USFWS midwater trawl sampling program. Survival indices of the paired CWT releases were calculated by dividing the number of fish recovered at Chipps Island from each tag code by the number released, corrected for the fraction of time and channel width sampled.

We performed diet comparisons on fall-run size juvenile salmon collected in beach seine samples. The stomachs were removed from fish and the contents were identified with a dissecting microscope. Up to ten individuals of each prey type encountered were measured and assigned a dry weight using regression equations from the literature. Feeding success was examined in two ways: (1) prey biomass estimates from the stomach content analysis; or (2) prey biomass estimates as a function of maximum theoretical consumption. For the first measure, we used the stomach content data to calculate total prey biomass for individual fish. A limitation of using prey biomass as a measure of feeding success between locations is that thermal history affects how consumption alters growth rate. As will be discussed in further detail, water temperatures were significantly higher in the Yolo Bypass floodplain than in the Sacramento River. To correct this problem, our second approach used bioenergetic modeling to incorporate the metabolic effects of water temperature. We used methods similar to Rand and Stewart (1998) to calculate a wet weight ration index, which uses prey biomass for each sampled individual as a proportion of the theoretical maximum daily consumption rate. The theoretical maximum daily consumption rate (Cmax) was modeled using Fish Bioenergetics 3.0 (Hanson and others 1997) using model parameters from Stewart and Ibarra (1991) and observed body size and water temperature at the time of collection in beach seine sampling. The model was run for individual fish to estimate the wet weight ration index, then the results were grouped and analyzed as for prey biomass.

Results and Discussion

The 1998 and 1999 results suggest chinook salmon that rear on the Yolo Bypass floodplain have higher growth rates than those that remain in the adjacent Sacramento River channels. Mean length increased faster in the Yolo Bypass during each study year (Figure 3) and CWT fish released in the Yolo Bypass were larger when they emigrated the Delta than those released in the Sacramento River (Table 1). It is possible that these observations are due to higher mortality rates of smaller individuals in the Yolo Bypass or of larger individuals in the Sacramento River, however we have no data or reasonable mechanisms to support this argument.

Apparent growth differences between the two areas are consistent with water temperature and stomach content results. We found that the Yolo Bypass floodplain had higher water temperatures (Figure 3) and young salmon ate significantly more prey (Figure 4) than in the Sacramento River. The wet weight ration indices calculated from bioenergetic modeling suggest increased prey availability in Yolo Bypass was sufficient to offset increased metabolic requirements from higher water temperatures (Figure 4). Higher water temperatures in the Yolo Bypass are expected as a result of the shallow depths on the broad floodplain. Increased feeding success in the Yolo Bypass is consistent with trends in prey availability. Although Yolo Bypass and Sacramento River had similar levels of zooplankton, Yolo Bypass had dramatically more dipteran prey in the drift and in the fish stomachs (DWR, unpublished data). Studies by Rondorf and others (1990) showed that zooplankton were the least-favored prey items in juvenile chinook salmon diets. The dominance of zooplankton in the diets of Sacramento River salmon therefore probably reflects relatively low availability of other more energetically valuable prey items such as dipterans.

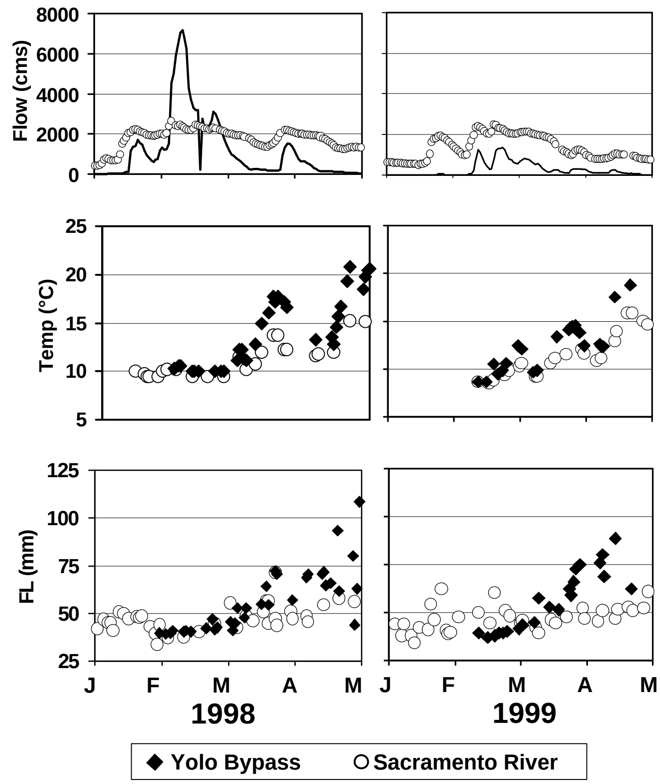

Figure 3 Fish size versus physical conditions in the Yolo Bypass and Sacramento River during winter and spring of 1998 and 1999: (A) mean daily flow (m^3/s or cms) in the Yolo Bypass (solid line) and Sacramento River (circles); (B) mean water temperature (°C) at Yolo Bypass (solid symbols) and Sacramento River (open symbols); (C) mean daily chinook salmon fork length for Yolo Bypass (solid symbols) and Sacramento River (open symbols) beach seine stations. For presentation purposes, only the daily mean fork lengths are shown; however, individual observations for February-March were used for statistical analyses. The regression slopes for log10-transformed Yolo Bypass and Sacramento River fork length data were significantly different (*t*-test, $p < 0.001$) in both years.

Table 1 Results of salmon collections at Chipps Island for 1998 and 1999 CWT groups released concurrently in the Yolo Bypass and Sacramento River[a]

	Fork length (mm)	*Migration time (d)*	*Survival index*	*Sample size*
Yolo Bypass				
1998	93.7 " 2.0	46.2 " 2.3	0.16	9
1999	89.0 " 2.6	58.2 " 2.8	0.09	9
Sacramento River				
1998	85.7 " 1.4	55.4 " 3.5	0.09	10
1999	82.1 " 1.7	58.6 " 4.1	0.07	8

[a] Mean values and standard errors of the mean are shown for fork length and migration time. Differences in fork length data tested with a two-way ANOVA were statistically significant for location ($p < 0.0006$) and year ($p < 0.05$), but not for the interaction between the two factors ($p < 0.78$). The migration time data were statistically significant for year (two-way ANOVA, $p < 0.02$), but not for location ($p < 0.15$) or the interaction between the two factors ($p < 0.18$).

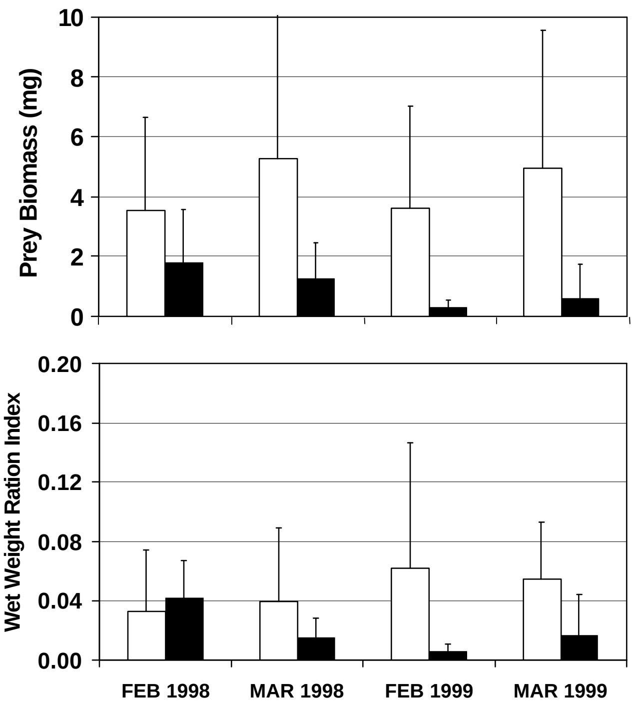

Figure 4 Feeding success results for Yolo Bypass (white bars) and Sacramento River (black bars) juvenile salmon during 1998 and 1999: (A) Estimated prey weights for stomach contents; (B) Wet weight ration indices. The two locations showed statistically significant (two-way ANOVA, $p < 0.001$) differences for each feeding success variable. The interaction between location and year was also statistically significant ($p < 0.005$) for the wet weight ration index only.

The survival indices for the Yolo Bypass release groups were somewhat higher than those for the Sacramento River (Table 1). However, recoveries were too low to determine whether the results reflect actual survival rates or random variation. Nonetheless, the hypothesis that floodplain rearing improves survival is substantiated by the previously-described growth data and bioenergetic modeling. Faster growth rates reflect improved habitat conditions, which would be expected to lead to better survival. Increased Yolo Bypass survival rates are also consistent with significantly faster migration rates in 1998 (Table 1), the likely result of which would be reduced exposure time to mortality risks in the Delta including predation and water diversions.

Improved survival is consistent with other habitat differences between the Yolo Bypass floodplain and Sacramento River channel. We estimate that complete inundation of the Yolo Bypass creates a wetted area approximately ten times larger than the reach of the Sacramento River we studied. Unlike the Sacramento River, much of the floodplain habitat consists of broad shoals comprised of soil and vegetation, typical of the low velocity conditions selected by young salmon (Everest and Chapman 1972). An increase in rearing area should reduce competition for food and space and perhaps reduce the probability of encounter with a predator. Migration through the Yolo Bypass corridor would also prevent fish from entering the central Delta, where there are various risks including entrainment mortality at Delta export facilities (Brandes and McClain forthcoming). On the other hand, the Yolo Bypass is a less stable environment, with stranding risks when floodwaters recede. The relatively well-drained topography of the Yolo Bypass floodplain may help to reduce stranding levels.

CONCLUSIONS

This study indicates that salmon which rear on the Yolo Bypass have better growth, feeding success and perhaps survival than those which migrate through the heavily channelized Sacramento River. These results provide new insight into the significance of floodplain habitat to salmon rearing, which have primarily been studied in estuarine and riverine habitat (Healy 1991; Kjelsen and others 1982). Our results are consistent with Sommer and others (1997), who found that the Yolo Bypass provides major spawning, rearing and foraging habitat for Sacramento splittail. Initial results from the Cosumnes River, an undammed watershed in the San Francisco Estuary show that floodplain rearing can enhance salmon growth and is not unique to the Yolo Bypass (Peter Moyle, University of California at Davis, personal communication). We believe these results demonstrate that floodplain habitat represents one of the most important habitat types for young salmon in the San Francisco Estuary and its tributaries.

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REFERENCES

Brandes PL, McLain JS. Forthcoming. Juvenile chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. California Department of Fish and Game, Fish Bulletin 179.

Everest FH, Chapman DW. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. J Fish Res Bd Canada 29(1):91–100.

Hanson PC, Johnson TB, Schindler DE, and Kitchell JF. 1997. Fish Bioenergetics 3.0. Center for Limnology, University of Wisconsin-Madison.

Healy MC. 1991. Life history of chinook salmon. In: Groot C, Margolis L, editors. Pacific salmon life histories. University of British Columbia: UBC Press. p 311–94.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecol Appl 5:272–89.

Junk WJ, Bayley PB, Sparks RE. 1989. The flood pulse concept in river-floodplain systems. Special publication. Can J Fish Aq Sci 106:110–27.

Kjelsen MA, Raquel PF, Fisher FW. 1982. Life history of fall-run juvenile chinook salmon, *Oncorhynchus tshawtscha*, in the Sacramento-San Joaquin Estuary, California. In: Kennedy VS, editor. Estuarine comparisons. New York (NY): Academic Press. p 393-411.

Rand PS, Stewart DJ. 1998. Dynamics of salmonine diets and foraging in Lake Ontario, 1983–1993: a test of a bioenergetic model prediction. Can J Fish Aq Sci 55:307–17.

Rondorf DW, Gray GA, Fairly RB. 1990. Feeding ecology of subyearling chinook salmon in riverine and reservoir habitats of the Columbia River. Trans Am Fish Soc 119:16–24.

Sommer T, Baxter R, Herbold, B. 1997. The resilience of splittail in the Sacramento-San Joaquin Estuary. Trans Am Fish Soc 126:961–76.

Stewart DJ, Ibarra M. 1991. Predation and production by salmonine fishes in Lake Michigan, 1978–1988. Can J Fish Aquat Sci 48:909–22.

Vannote RL, Minshall GW, Cummins KW, Sedell FR, Cushing CE. 1980. The river continuum concept. Can J Fish Aquat Sci 37:130–7.

MONITORING THE DISTRIBUTION AND MIGRATION OF DELTA SMELT (*HYPOMESUS TRANSPACIFICUS*): ARE ADDITIONAL MIDWATER TRAWL STATIONS USEFUL?

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INTRODUCTION

The decline of delta smelt (*Hypomesus transpacificus*) (Sweetnam and Stevens 1993) prompted the Department of Fish and Game (DFG) to increase sampling effort to better describe delta smelt distribution and migration. To do this, DFG added 19 stations to the Midwater Trawl Survey (MWT) sampling schedule in 1990 and 1991 and has continuously sampled 16 of them (Table 1). These stations are not used in calculating the Fall Midwater Trawl index of abundance of delta smelt; they are used solely to describe delta smelt distribution and migration. Given the increasing demands on Interagency Ecological Program (IEP) resources, eliminating superfluous sampling is a priority. However, an evaluation of the usefulness of these additional stations has not been attempted. This evaluation is made to determine whether further sampling of these 16 additional stations is warranted. I analyzed the distribution of delta smelt at these stations and the ability of the MWT to track the spawning migration in Cache and Steamboat sloughs and the lower Sacramento River.

METHODS

Distribution Analysis

I organized nine years of delta smelt catch data in the MWT database from September 1990 to March 1999 into MWT "survey years" which begin in July (survey 1) and end in the following June (survey 12). For example, surveys conducted in September (survey 3) 1991 and February (survey 8) 1992 would both be in survey year 1991. Stations 70, 924, and 925 were excluded from all analyses because combined they were sampled only 21 times and no delta smelt were caught at them. These data were used to conduct two distribution analyses: "coarse" (by area) and "fine" (by station).

Table 1 Characteristics of stations added to the DFG midwater trawl survey to facilitate monitoring of delta smelt

Station	*Average Depth (ft)*	*Month and year added*[a]	*Location*	*Area*[b]
340	16	Reference station	Napa River at Mare Island, above fixed bridge	*2*
341	20	Sep 1991	Napa River, 0.7 km upstream of Highway 37	*7*
711	39	Reference station	Sacramento River, upstream of light 36	*3*
712	12	Oct 1990	Steamboat Slough, between siphons	*4*
713	35	Sep 1990	Cache Slough, north of light 43	*4*
715	28	Sep 1990	Cache Slough, north of light 47	*4*
716	19	Sep 1991	Cache Slough, north of Cable Ferry 1 & 51	*4*
717	12	Sep 1990	Sacramento River at Grand Island, below Isleton	*4*
72	13	Jan 1991	Sacramento River, south of LDG 40	*5*
725	18	Jan 1991	Sacramento River at Georgiana Slough	*5*
73	19	Jan 1991	Sacramento River at Vorden	*5*
735	20	Jan 1991	Sacramento River 1,000 yds above Sutter Slough	*5*
74	19	Jan 1991	Sacramento River at Rosebud Landing	*5*
903	12	Reference station	Mokelumne River, 1,600 yds upstream of the San Joaquin River	*3*
906	35	Reference station	San Joaquin River, between lights 5 & 6	*3*
919	17	Jan 1991	Little Potato Slough, 1,200 yds north of White Slough	*6*
920	17	Feb 1991	South Fork Mokelumne River at Sycamore Slough	*6*
921	12	Feb 1991	South Fork Mokelumne River at Hog Slough	*6*
922	12	Jan 1991	South Fork Mokelumne River at Beaver Slough	*6*
923	17	Feb 1991	Mokelumne River in bend above South Fork Mokelumne River	*6*

a Reference Stations 340, 711, 903, and 906 are listed for comparison.
b See text and Figure 1 for area descriptions and locations.

The coarse distribution analysis was done by grouping MWT stations for the above survey years into seven areas (Figure 1), containing the following stations:

- Area 1: San Pablo Bay, including all stations downstream of the Carquinez Strait (downstream of Station 339).
- Area 2: Suisun Bay, from Broad Slough to the western end of the Carquinez Strait, including the lower Napa River (Station 340), and Montezuma Slough.
- Area 3: the Delta; the lower Sacramento River (Stations 701–711), the lower San Joaquin River and the eastern Delta.
- Area 4: the lower Sacramento River, Stations 712, 713, 715, 716, and 717, including Cache and Steamboat sloughs.
- Area 5: the upper Sacramento River, Stations 72, 725, 73, 735, and 74.
- Area 6: the Mokelumne River, Stations 919 to 923.
- Area 7: the Napa River, Station 341.

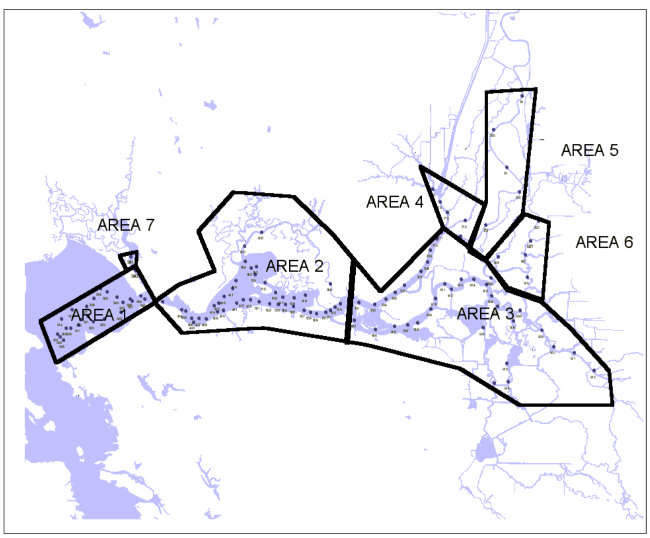

Figure 1 Partitioning of midwater trawl stations into areas used in the coarse distribution analysis. See text for area descriptions.

I calculated the percent of delta smelt caught in each area for all survey years. Since the number of stations in each area is unequal and in some survey years some stations were not sampled, I also calculated catch/tow (mean catch) for all areas in all survey years.

The fine distribution analysis consisted of calculating for each station in Areas 4–7 the number of delta smelt caught (annual catch) and the catch/tow (mean catch) for each survey year and for all survey years combined. This analysis was also conducted on four reference stations used in calculating the MWT fall index for comparison purposes. The reference stations were selected by their geographical proximity to the 16 additional stations (Table 1).

Spawning Migration Analysis

For the spawning migration analysis I log-transformed and standardized the catch data by survey year for Stations 712, 713, 715, 716, and 717, survey years 1990–1999 and surveys 3 through 9 (September through March). I used the following criteria for detecting a spawning pulse: a standardized value of 2 or greater that had occurred during January, February, or March.

RESULTS

Distribution Analysis

The coarse analysis indicated that most of delta smelt were caught in Susiun Bay (Area 2) and the delta (Area 3) (Table 2). The only other areas that had > 5% of any year's catch were the lower Sacramento River (Area 4) and the Napa River (Area 7) and then only in three out of nine years (Table 2). The mean catch (Table 3) agrees with these results. Only in survey years 1990 and 1991 did the lower Sacramento River (Area 4) have mean catches above 1.0 (Table 3), possibly reflecting flow conditions at the time (calendar years 1990 through 1992 were critically dry years) and only in survey years 1990, 1991,1992, 1996, and 1998 did the mean catch exceed that of Suisun Bay (Area 2), or the Delta (Area 3) (Table 3). The Napa River (Area 7) mean catch results (mean catch = 10.00 fish/tow in survey year 1995 and 1.20 in survey year 1998, Table 3) indicated that occasionally the Napa River is extensively used by delta smelt.

The other areas (San Pablo Bay–Area 1, the upper Sacramento River–Area 5, and the Mokelumne River–Area 6) were used lightly by delta smelt (Tables 2 and 3) with the Mokelumne River (Area 6) being the most consistently used of the remaining 3 areas. Only in survey years 1990 and 1992 did the Mokelumne River (Area 6) have a higher mean catch than Suisun Bay (Area 2) but not the Delta (Area 3) (Table 3).

The "fine" analysis indicated that the majority of delta smelt catches outside of Areas 1–3 (areas containing the stations used in calculating the MWT index of abundance) were primarily at 7 of the 16 added stations: Station 923 (Area 6, Table 4), Stations 712, 713, 715, 716, and 717 (Area 4, Table 5), and Station 341 (Area 7, Table 6). These seven stations contributed 287 (93.8%) of the 306 total delta smelt caught at these 16 stations. Two stations, 715 and 716, contributed 151 (49.3%) of the 306 smelt caught and most of these fish (34.3%, 105 fish) were taken in survey years 1990, (Station 715), 1991 (Station 716), and 1993 (Stations 715 and 716) (Table 5). The remaining nine stations usually had annual catches of zero or one and correspondingly zero or low catch per tow values (Tables 4–6).

Spawning Migration Analysis

Out of 284 samples (tows) in the lower Sacramento River (Area 4), only 20 recorded a standard deviation greater than 2.0 (Table 7). Of these 20, only 14 occurred from January through March, and thus met the criteria for a spawning pulse (Table 7). However, given the low station and seasonal catches that occurred from survey years 1994 through 1998, January 1991 and February 1994 were likely to be the only observable spawning pulses during this period.

Table 2 Percentage of delta smelt catch at Areas 1–7 for survey years 1990–1998

	Area						
Survey year	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1990	0.0	15.0	76.9	7.4	0.0	0.7	—[a]
1991	0.0	10.6	81.1	8.0	0.0	0.3	0.0
1992	0.0	16.9	76.4	4.1	0.0	2.6	0.0
1993	0.0	55.2	40.9	3.3	0.3	0.3	0.0
1994	0.0	54.0	42.6	2.5	0.5	0.5	0.0
1995	4.6	79.7	8.8	1.1	0.0	0.2	5.7
1996	0.0	75.9	16.9	3.6	1.5	2.1	0.0
1997	2.6	52.0	43.3	0.8	0.0	1.3	0.0
1998	1.1	85.3	7.9	3.8	0.0	0.5	1.4

[a] Indicates that a particular area was not sampled in that survey year.

Table 3 Mean catch of delta smelt catch at Areas 1–7 for survey years 1990–1998

	Area						
Survey year	*1*	*2*	*3*	*4*	*5*	*6*	*7*
1990	0.00	0.31	1.83	1.52	0.00	0.33	—[a]
1991	0.00	0.24	1.99	1.40	0.00	0.05	0.00
1992	0.00	0.09	0.48	0.18	0.00	0.11	0.00
1993	0.00	1.90	1.69	0.98	0.18	0.09	0.00
1994	0.00	0.29	0.27	0.11	0.03	0.02	0.00
1995	0.40	3.31	0.44	0.38	0.00	0.06	10.00
1996	0.00	0.50	0.14	0.20	0.11	0.12	0.00
1997	0.06	0.67	0.67	0.09	0.00	0.14	0.00
1998	0.04	1.50	0.18	0.71	0.00	0.08	1.20

[a] Indicates that a particular area was not sampled in that survey year.

Table 4 Catch (C) and catch per tow (C/T) of delta smelt at Stations 903, 906, and 919 to 923 for survey years 1990–1998 of the DFG midwater trawl survey

	Sta. 903		*Sta. 906*		*Sta. 919*		*Sta. 920*		*Sta. 921*		*Sta. 922*		*Sta. 923*	
Survey year	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*
1990	1	0.14	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	4	2.00
1991	0	0.00	0	0.00	1	0.13	0	0.00	0	0.00	0	0.00	1	0.13
1992	0	0.00	1	0.11	0	0.00	3	0.33	0	0.00	1	0.13	1	0.11
1993	0	0.00	0	0.00	0	0.00	1	0.11	1	0.11	1	0.11	1	0.11
1994	1	0.11	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.11
1995	2	0.29	1	0.14	0	0.00	0	0.00	0	0.00	0	0.00	2	0.29
1996	0	0.00	1	0.14	0	0.00	1	0.14	0	0.00	0	0.00	3	0.43
1997	2	0.29	0	0.00	0	0.00	1	0.14	0	0.00	0	0.00	4	0.57
1998	1	0.17	0	0.00	0	0.00	0	0.00	1	0.20	0	0.00	1	0.20
Total	7	0.10	3	0.04	1	0.02	6	0.10	2	0.03	2	0.03	18	0.29

Table 5 Catch (C), and catch per tow (C/T) of delta smelt at Stations 711 to 713, and 715 to 717 for survey years 1990–1998 of the DFG midwater trawl survey

	Sta. 711		*Sta. 712*		*Sta. 713*		*Sta. 715*		*Sta. 716*		*Sta. 717*	
Survey year	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*
1990	2	0.29	9	1.50	1	0.14	29	4.14	—[a]	2	0.29	
1991	3	0.38	3	0.38	2	0.25	9	1.13	37	4.63	5	0.63
1992	1	0.13	0	0.00	1	0.11	2	0.22	3	0.33	2	0.22
1993	9	1.00	3	0.33	1	0.11	19	2.11	20	2.22	0	0.00
1994	0	0.00	0	0.00	0	0.00	2	0.22	3	0.33	0	0.00
1995	3	0.43	0	0.00	2	0.29	5	0.71	6	1.00	0	0.00
1996	2	0.29	2	0.29	0	0.00	4	0.57	1	0.14	0	0.00
1997	2	0.29	0	0.00	0	0.00	1	0.14	1	0.14	1	0.14
1998	1	0.17	0	0.00	7	1.40	8	1.60	1	0.20	1	0.20
Total	23	0.34	17	0.26	14	0.21	79	1.16	72	1.20	11	0.16

[a] Indicates that a station was not sampled.

Table 6 Catch (C) and catch per tow (C/T) of delta smelt at Stations 340, 341, 72, 725, 73, 735, and 74 for survey years 1990–1998 of the DFG midwater trawl survey

	Sta. 340		*Sta. 341*		*Sta. 72*		*Sta. 725*		*Sta. 73*		*Sta. 735*		*Sta. 74*	
Survey year	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*	*C*	*C/T*
1990	0	0.00	—[a]	—[a]	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
1991	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
1992	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
1993	0	0.00	0	0.00	0	0.00	0	0.00	2	0.50	1	0.25	1	0.25
1994	2	0.25	0	0.00	1	0.13	0	0.00	0	0.00	0	0.00	0	0.00
1995	29	4.14	70	10.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
1996	2	0.29	0	0.00	0	0.00	2	0.33	0	0.00	0	0.00	1	0.20
1997	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
1998	1	0.17	6	1.20	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	34	0.54	76	1.41	1	0.02	2	0.04	2	0.04	1	0.02	2	0.04

[a] Indicates that a station was not sampled.

Table 7 Catch, total season catch, month and standard deviation (ln[catch]) for delta smelt stations used in the migration analysis

Station	Survey year	Month & year	Catch	Season Catch	Std. Dev.
712	1990	Jan 1991	7	41	2.26[a]
715	1990	Jan 1991	29	41	3.96[a]
716	1991	Oct 1991	11	55	2.45
716	1991	Nov 1991	12	55	2.55
716	1993	Feb 1994	17	29	4.16[a]
715	1993	Mar 1994	4	29	2.13
716	1994	Dec 1994	2	4	4.25
715	1994	Jan 1995	1	4	2.57
716	1994	Jan 1995	1	4	2.57
716	1995	Sep 1995	5	13	3.59
713	1995	Oct 1995	2	13	2.04
715	1995	Oct 1995	2	13	2.04
715	1995	Jan 1996	2	13	2.04
712	1996	Mar 1997	2	7	2.69
715	1996	Mar 1997	4	7	4.08
715	1997	Jan 1998	1	3	2.95
716	1997	Jan 1998	1	3	2.95
717	1997	Mar 1998	1	3	2.95
713	1998	Mar 1999	7	17	3.00
715	1998	Mar 1999	7	17	3.00

[a] Indicates that a particular station was scored as a spawning pulse.

DISCUSSION

Discussion of these results and data must take into account the catch efficiency of the MWT. Low catch efficiency would lead to small or zero catches of delta smelt and bias the results. There are two possible sources of inefficiency: loss through the net and net avoidance. Loss of delta smelt through the cod end of the trawl has been observed. In 1991, Sweetnam (unpublished data) conducted experimental tows with the cod end covered with a bag made from 0.1250-inch bobbit (the cod end is 0.5-inch mesh). The average catch was 13.67 delta smelt/tow (standard deviation = 9.07) uncovered and 85.58 delta smelt/tow (standard deviation = 80.22) covered, implying high losses through the cod end of the trawl. Net avoidance has yet to be measured.

Possible ways to improve the MWT's efficiency are to sample more stations, sample more often, and use a cod end with a finer mesh. Schaffter (1980) recorded an average weekly catch of 2.6 delta smelt/10 minute tow in the Sacramento River between Clarksburg and Walnut Grove in April 1973 using a MWT. However, at times Schaffter (1980) was conducting over 10 tows a day and in some instances sampling 5 days a week (Raymond Schaffter, personal communication, see "Notes"), indicating the high level of effort needed to detect delta smelt, especially a spawning pulse. However, more intense sampling (both spatially and temporally) is not practical given the number of stations already sampled. Changing the cod end to a smaller mesh would retain more delta smelt, but net correction factors would have to be developed to correct historical data. This would require an intensive net comparison study. Even with net correction factors there would be no easy way to correct for zero catches in the database and net correction factors would have to be developed for every species that the MWT catches including striped bass (*Morone saxatilis*), longfin smelt (*Spirinchus thaleichthys*), American shad (*Alosa sapidissima*), and Sacramento splittail (*Pogonichthys macrolepidotus*). Obviously, there is no easy way to "fix" the MWT.

Kodiak trawling (towing a net between two boats) would be a better alternative to the MWT in certain circumstances. Kodiak trawling has been observed to catch substantially more delta smelt than the MWT (Geir Aasen, personal communication, see "Notes"). A comparison study in 1994 revealed that the Kodiak trawl caught roughly 100 times the number of delta smelt that the MWT did (DFG 1994 unpublished data). However, only five tows were conducted. A more extensive comparison study would be necessary before the MWT's catches could be corrected, and there is no easy way to correct a MWT catch of zero. There is also the difficulty of using a Kodiak trawling in some parts of the estuary (such as Suisun Bay). The increased expense associated with kodiak trawling (two boats compared to one and five crew members compared to three) is also a consideration. The best strategy would be to use a Kodiak trawl in place of the MWT at selected stations where more accurate information is essential. In particular, Stations 72, 725, 73, 735, 74, and 919–922 have provided little information on delta smelt distribution and should be removed from the MWT station schedule and sampled by Kodiak trawl. If delta smelt are using the habitat at these stations, the density is so low that the MWT cannot distinguish it from zero most of the time, but the Kodiak trawl might.

Despite its shortcomings, the MWT can still provide useful distribution information on a coarse scale. The MWT was able to determine the overall distribution of delta smelt and that they were concentrated in Areas 2 and 3. These areas are primarily in the brackish habitat that delta smelt prefer (Ganssle 1966; Moyle 1976; Sweetnam and Stevens 1993) and have many closely-spaced stations (Figure 1). This gives the MWT more chances to encounter schools of delta smelt. Also, these areas contain stations used in calculating the MWT abundance index and provides for long-term monitoring of delta smelt.

Areas 4, 6, and 7 have been useful in describing the distribution of delta smelt, but only at Stations 712, 713, 715, 716, 717, 923, and 341, which have provided useful information about delta smelt distribution and should remain on the MWT station schedule. Stations 712, 713, 715, 716, and 717 (Area 4) were consistently used by delta smelt (Tables 2 and 3) and in 1990 and 1991 the catch/tow values for Area 4 were greater than for Area 2, implying that the preferred habitat for delta smelt may have shifted upstream. Area 6 was also used by delta smelt but not as much as Areas 2, 3, or 4 (Tables 2 and 3) and was used almost exclusively at Station 923 (Table 4). When Area 7 (Station 341) was used (1995 and 1998), it was used extensively with high catch per tow values (Tables 2 and 3).

The use of stations in Area 4 to monitor the spawning migration of delta smelt is problematic at best. The situation is even more confused as it is not known whether delta smelt spawn in Area 4 every year (Dale Sweetnam, personal communication, see "Notes") More stations that are sampled more frequently would be necessary to describe the spawning migration in Area 2 (see above). Therefore, I recommend that data from the MWT should not be used to predict or determine the status of the spawning migration, but be limited to descriptions of abundance and distribution. Area 4 would also be another candidate for Kodiak trawling (see above).

CONCLUSION

The MWT provides useful information on the distribution of delta smelt. The loss of Stations 72, 725, 73, 735, 74, and 919–922 will not adversely affect the MWT's current usefulness but will make more efficient use of our limited sampling resources.

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REFERENCES

Ganssle D. 1966. Fishes and decapods of San Pablo and Suisun bays. In: Kelley DW, editor. Ecological Studies of the Sacramento-San Joaquin Estuary. Part 1. California Department of Fish and Game, Fish Bulletin 133. p 64–94.

Moyle PB. 1976. Inland fishes of California. Berkeley (CA): University of California Press. 405 p.

Schaffter RG. 1980. Fish occurrence, size, and distribution in the Sacramento River near Hood, California, during 1973 and 1974. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report Number 80-3.

Sweetnam DA, Stevens DE. 1993. Report to the Fish and Game Commission: a status review of the status of delta smelt (*Hypomesus transpacificus*) in California. Candidate Species Report 93-DS.

NOTES

Raymond Schaffter (California Department of Fish and Game). Conversation with author in February 2000.

Geir Aasen (California Department of Fish and Game). Conversation with author in February 2000.

Dale Sweetnam (California Department of Fish and Game). Conversation with author in February 2000.

The Sacramento-San Joaquin Delta Largemouth Bass Fishery

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Introduction

A National survey estimated that in 1996, anglers spent over $3.3 billion on trip-related fishing activities in California (USFWS and USDOC 1998). Although comparable figures are not available, Fletcher and King (1988) indicated that a large portion of California anglers target black bass (*Micropterus* sp.). Largemouth bass (*Micropterus salmoides*) and smallmouth bass (*M. dolomieu*) were introduced into California in the late 1800s while spotted (*M. punctulatus*) and redeye bass (*M. coosae*) followed several decades later. No records exist to indicate when black bass first reached the Sacramento-San Joaquin Delta, but based on early records of the distribution of largemouth and smallmouth bass in California, it is not unreasonable to speculate that populations of both largemouth and smallmouth bass developed in the Delta in the early 1900s (personal communication Almo Cordone, Senior Fishery Biologist retired, DFG). Today, largemouth bass and to a lesser extent smallmouth and spotted bass, support a popular sport fishery in the Delta.

During the past 30 years, interest in black bass fishing and competitive fishing has increased significantly (Holbrook 1975; Schramm and others 1991). The first publicized black bass tournament was conducted in Arkansas in 1968 and tournaments became popular in California in the 1970s and continue today. Tournaments are sponsored by private organizations or businesses for profit, and by non-profit groups. Contests are usually designated as either team tournaments or draw tournaments and are fished from boats. Only a few shore-based black bass tournaments have been conducted at California reservoirs. Team tournaments are usually conducted with two anglers fishing from one boat as a team. Their catch of bass (not exceeding the daily bag limit for each individual) is weighed together, and teams compete against one another based on total weight of their catch. In draw tournaments, anglers draw daily boat partners and anglers compete individually. Although the two anglers fish from the same boat, their daily catches may be weighed separately or, in some multi-day draw tournaments, the weight of the catch for both anglers is combined for each day, and partners are rotated each day of the contest. In some special events, a single competitor may be paired with a non-fishing observer. Fishery managers have used black bass tournaments to help estimate fish abundance and provide trend information on fishing success (Aggus and Rainwater 1975; Willis and Hartmann 1986).

Anglers have fished for black bass in the Delta for many years and the fishery has become more popular during the past two decades. Drought conditions and low reservoir elevations in California in the mid- to late 1980s prevented use of launching ramps at many popular reservoirs and diverted black bass tournaments to the Delta. Although all four species of black bass that occur in California can be found in the Delta or its tributaries, the majority of black bass weighed-in during tournaments are largemouth bass. Tournament anglers often target largemouth bass because they are more numerous and weigh more for a given length than the other species.

Methods

During the period 1975–1989, under authority provided in the Fish and Game Code of California, sponsors of any fishing contest in California that offered prizes or other inducements exceeding $200 in total value were required to obtain a permit from the California Department of Fish and Game (DFG). Before 1986, individual prizes offered in team tournaments could not exceed $200. Consequently, team tournaments were not issued permits and did not submit reports. In 1986, the restriction was eliminated and sponsors applied for and were issued permits for team tournaments offering higher prize values. Beginning in 1990, anyone offering prizes or inducements to take game fish is required to obtain a permit from the DFG.

All permitted tournaments included in the analysis were “weigh-in” type contests in which the fish were brought daily by contestants to a central weigh-in site at a specified time. Competitors were required to comply with all state fishing regulations. The statewide daily bag limit was five fish per angler. Although a minimum size limit was not in effect during the period covered, all tournaments employed a 305 mm minimum total length (TL) requirement. State regulations prohibit the use of live bait in tournaments and boats participating in the tournament were required to have an operational, aerated live well to keep the bass alive. Additional “special conditions” to improve the survival of released bass were appended to all permits beginning in 1988. Special conditions” included transportation of all bass to and from the weigh-in site in water-filled containers; a three-minute maximum time limit that bass could be held in the containers; a maximum of five fish per container; a requirement that any bass greater than 5 lbs (2.27 kg) be held in an individual container; the use of holding tanks near the weigh-in site; and a maximum allowable fishing time of six hours between weigh-ins for tournaments conducted between June 15 and September 15.

Beginning in 1985, tournament sponsors issued a permit also received a sponsor’s report form and were required to return the completed form to the DFG. If sponsors did not return the required report, contact was made in an attempt to retrieve the information. In some instances, sponsors were not reachable and information could not be obtained. Reports included information on the date of the tournament, number of competitors, duration of the tournament, total catch, weight of the total catch, species and weight of the largest individual fish, and total number of fish released alive. Information from permits and reports was entered into databases and analyzed using personal computers.

I analyzed all permits issued and reports received for the calendar years 1985–1999 for the Delta. Canceled tournaments were deleted from the database. Information from the sponsor’s reports was summarized to provide data on angler effort and catch for each year. To account for permitted tournaments that did not return completed reports, total effort and catch were estimated by expanding the reported information by the total number of days of fishing effort indicated on the applications.

RESULTS

The DFG issued 1,681 permits during 1985–1999 for black bass tournaments conducted in the Delta (Figure 1). Sponsors returned reports for 1,143 (68%) of these contests. Sponsors reported 2,009 days fished, representing 845,036 angler-hours of effort, and 171,240 black bass weighed-in during the same period (Table 1).

The annual catch per hour (CPH) for reported contests ranged from a low of 0.106 in 1989 to a high of 0.481 in 1985. In 1985, only one report was received for only 18 individuals fishing. The next highest CPH occurred in 1999 and was estimated to be 0.258. The estimated total effort during the 14-year period analyzed was slightly more than 1.4 million angler-hours, representing 114,820 angler days, during which 287,982 black bass were estimated to be weighed-in.

The mean weight of bass weighed-in was 1.68 lbs (0.756 kg) and ranged from a low of 1.45 lbs (0.653 kg) in 1994 to a high of 3.21 lbs (1.44 kg) in 1985. The largest black bass reported weighed-in during a tournament weighed 15.54 lbs (6.99 kg). A total of 33 largemouth bass >10 lbs (4.5 kg) has been reported weighed-in during tournaments. The majority (90%) of the large bass has been reported during the past five years (Figure 2).

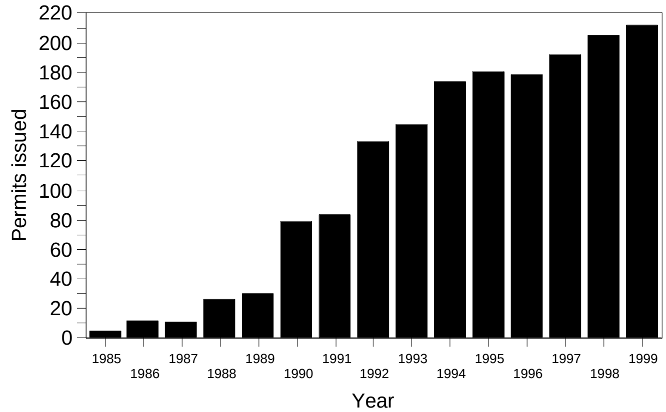

Figure 1 Number of permits for black bass tournaments issued by the DFG for the Sacramento-San Joaquin Delta, 1985–1999

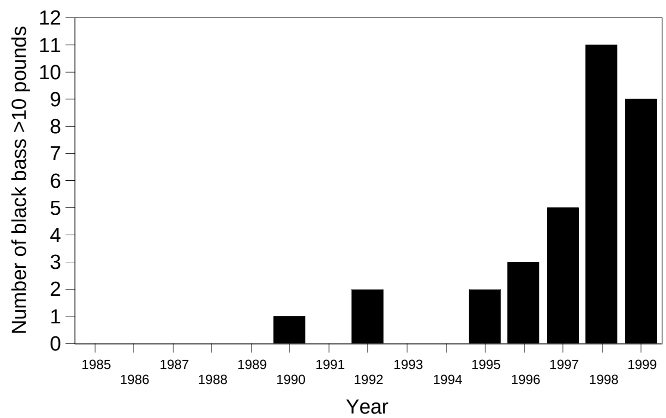

Figure 2 Number of largemouth bass (>10 lbs) reported caught in black bass tournaments in the Sacramento-San Joaquin Delta, 1985–1999

Table 1 Reported and estimated effort and catch of black bass from tournaments conducted in the Sacramento-San Joaquin Delta, 1985–1999

Year	*Total no. of days fished*	*No. of days with reported information*	*No. of bass reported weighed-in*	*No. of participants reported fishing*	*Total hrs reported fished*	*Mean annual catch per hr*	*Total annual weight of fish caught*	*Mean weight of black bass weighed-in (lbs)*	*Est. total hrs of annual effort*	*Est. no. of black bass caught*	*Est. days of effort*
1985	6	1	78	18	162	0.481	250	3.21	972	468	108
1986	13	5	1,811	901	8,380	0.216	3,045	1.68	21,787	4,709	2,343
1987	13	10	2,657	1,393	15,219	0.175	4,783	1.80	19,785	3,454	1,811
1988	30	27	4,990	2,868	31,915	0.156	9,267	1.86	35,461	5,544	3,187
1989	39	30	6,004	2,774	56,853	0.106	11,305	1.88	73,909	7,805	3,606
1990	95	58	10,237	3,630	53,637	0.191	19,019	1.86	87,854	16,768	5,946
1991	109	73	11,280	4,810	69,052	0.163	19,862	1.76	103,105	16,843	7,182
1992	157	67	6,322	3,912	39,796	0.159	13,078	2.07	93,253	14,814	9,167
1993	182	124	17,414	6,880	84,762	0.205	33,488	1.92	124,409	25,559	10,098
1994	216	132	21,286	7,319	89,685	0.237	30,837	1.45	146,757	34,832	11,977
1995	220	120	18,630	6,280	77,578	0.240	26,151	1.40	142,226	34,155	11,513
1996	214	162	18,647	6,859	84,988	0.219	31,261	1.68	112,268	24,632	9,061
1997	230	118	17,616	6,106	79,892	0.220	27,692	1.57	155,722	34,336	11,902
1998	238	142	20,318	7,417	99,125	0.205	36,185	1.78	166,139	34,054	12,431
1999	247	97	13,950	5,473	53,992	0.258	21,183	1.52	137,485	35,522	13,936
Totals/ means	2,009	1,166	171,240	66,640	845,036	0.203	287,406	1.68	1,421,133	287,982	114,820

DISCUSSION

The number of days of fishing tournaments conducted in the Delta has increased since 1985. During the past two years the DFG has issued permits for more than 200 individual contests annually. Total effort expressed as angler days has increased during the same period and exceeded 10,000 days in all but one year since 1993. A portion of the increased use can be attributed to the change in regulations in 1990 that captured the smaller, club-type contests in the permitting and reporting process.

Angler catch rates estimated from reports varied during the past 14 years but exceed 0.20 fish per hour during all of the past seven years. The mean weight of black bass reported weighed-in has also varied. Like statewide black bass tournaments, there appears to be a negative correlation between CPH and mean weight of black bass caught and weighed-in during tournaments (Figure 3). Nonetheless, only a few waters in California consistently produce mean annual catch rates for black bass exceeding 0.20 fish per hour for fishing contests and mean black bass weights exceeding 1.5 lbs (0.68 kg). Also of interest is the increased number of largemouth bass >10 lbs (4.5 kg) reported. This increase follows a similar trend observed for many California reservoir black bass fisheries following the introduction of Florida largemouth bass (*M. s. floridanus*).

The DFG introduced Florida largemouth bass into the Delta in the early 1980s and again in 1989. Analysis of the genetic composition of the largemouth bass population indicated that a portion of the population demonstrate Florida-like alleles (Gall 1999). The largest largemouth bass reported caught from the Delta was taken during a tournament in April 2000 and weighed 17.57 lbs (7.907 kg).

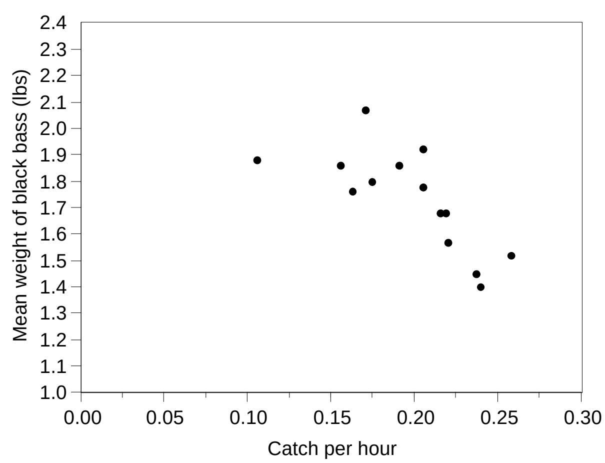

Figure 3 Relationship between catch per hour and mean weight of largemouth bass weighed-in during black bass tournaments in the Delta, 1985–1999

Effort, catch, and mortality estimates from black bass tournaments have been used for developing fisheries management plans and regulating tournament effort. Schramm and others (1991) reported that 76% of the inland agencies surveyed obtained some type of statistics from competitive fishing events. In most cases, reporting procedures relied on voluntary compliance (Willis and Hartmann 1986; Whitworth 1987). DFG (1995) has used information from black bass tournaments to provide general information on the black bass fishery and guide management decisions.

Many factors influenced the quality of the black bass fishery in terms of catch rates and average size bass caught. The Delta fishery has shown improvements not demonstrated by other California black bass fisheries during the same period. Cold water inflows into the Delta influence growth and survival of warmwater species like largemouth bass. During years with high inflow and cold water, black bass growth and survival are reduced. In years with low inflow, largemouth bass habitat is improved, and growth and survival improves. The most recent drought in California created low reservoir water levels that subsequently affected the quality of those black bass fisheries. However, water levels in the Delta were not influenced during the same period and the reduced cold water inflow meant enhanced habitat conditions for black bass. Those improvements have translated into higher catch rates and an improved largemouth bass fishery as demonstrated by tournament results.

Acknowledgments

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References

Aggus LF, Rainwater WC. 1975. Estimating largemouth bass population in reservoirs from catches in angling tournaments. Proc Ann Conf Southeast Assoc Game Fish Comm 29:106–18.

Fletcher JE, King M. 1988. Attitudes and preferences of inland anglers in the State of California, final report. Sacramento (CA): California Department of Fish and Game. 167 p.

[DFG] California Department of Fish and Game. 1995. Assessment of California black bass angling regulations. California Department of Fish and Game, Inland Fisheries. 129 p.

Holbrook JA. 1975. Bass fishing tournaments. In: Clepper H, editor. Black bass biology and management. Bethesda (MD): American Fishery Society. p 408–15.

Gall AE. 1999. Genetic analysis of largemouth bass, *Micropterus salmoides*, sampled from California Reservoirs: contributions of northern and Florida strains. DFG Interagency Agreement. Final Report No. FG4043IF. Sacramento (CA): California Department of Fish and Game.

Schramm H Jr., Armstrong ML, Funicelli NA, Green DM, Lee DP, Manns RE Jr., Taubert BD, Waters SJ. 1991. The status of competitive fishing in North America. Fisheries 16(3):4–12.

Seidensticker EP. 1975. Mortality of largemouth bass for two tournaments utilizing a "don't kill your catch" program. Proc Ann Conf Southeast Assoc Game Fish Comm 28:83–6.

[USFWS and USDOC] US Fish and Wildlife Service and US Department of Commerce, Bureau of the Census. 1998. 1996 National Survey of Fishing, Hunting, and Wildlife–Assoicated Recreation–California. FHW/96-CA. 47 p.

Whitworth DW. 1987. Survey of largemouth bass tournament fishing in Texas: 1985. Austin (TX): Texas Parks and Wildlife. 89 p.

Willis DW, Hartmann RF. 1986. The Kansas bass tournament monitoring program. Fisheries 11(3):7–10.

Notes

Almo Cordone (California Department of Fish and Game, retired). Conversation with author in June 2000.

Estimating Population Level Effects on Salmon Smolts and Estuarine Species for Environmental Requirements Affecting Delta Water Project Operations

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Abstract

Water project operations in the Sacramento-San Joaquin Delta are constrained by regulatory requirements set to protect fish. The following requirements apply:

Curtailment of the rate of export at the federal (Tracy) and State (Banks) pumping plants in the southern Delta.

Maintenance of flows above specified minimums in the Sacramento and San Joaquin Rivers.

Achieving no less than a specified number of days in February through March that the 2 ppt salinity line must be downstream of certain locations. This requirement, known as the "X2" requirement, essentially maintains the rate of freshwater outflow from the Delta above specified minimums.

Closure of the gates at the Delta Cross Channel, a channel connecting the Sacramento River to the Mokelumne River and central Delta.

These requirements have significant effects on the water deliveries of the State Water Project and the Central Valley Project. The requirements have been assumed to have significant benefits for fish, that is, to increase the population of important species. However, estimates of population level effects have not generally been made. Nor have estimates been made of actions required to achieve specific increases in population size. This article presents such estimates for salmon and for the estuarine species affected by the X2 requirement.

Results of these analyses are summarized in Table 1. The summary shows estimates for the amount of water associated with a 1% increase in population. The table also shows the cost associated with those amounts, assuming water costs $100 per acre-foot. The tabulated values are for "average" rates of export (4,000 cfs) and river flow or Delta outflow (20,000 cfs). The notes in the table indicate how the amounts of water change with higher or lower export rates or flowrates. Amounts of water associated with larger population increases are proportional to the percent increase. For example, a 5% increase would be associated with five times as much water as shown in Table 1.

Note that these amounts of water do not necessarily result in a water supply loss equal to the amounts shown. Sometimes, the water supply loss can be made up later (or earlier) in the year. Therefore, these amounts should be considered as a measure of the risk of water supply loss rather than a measure of the amounts sure to be lost.

Key assumptions underlay these estimates:

Data collected over the last 15 to 25 years demonstrate relationships between population levels and the requirements listed above. The validity of these relationships is a matter of dispute. However, in this article, I set that dispute aside and used those relationships to determine how changes in population were associated with changes in the requirements.

All population changes are related to the total population of the year class affected by the requirement. For example, a 1% change in population for emigrating Sacramento River fall-run salmon smolts means that of all of those fall-run smolts entering the Delta, 1% more survive passage through the Delta.

The requirements (for export curtailments, river flow increases, or increases in Delta outflow) apply over the periods shown, when most of the species are affected by the requirements. Requirements could be applied over shorter periods of time, but the fraction of the population affected would be smaller as would the amount of water associated with the change. Also, such requirements, by benefiting only a portion of the population, could affect genetic diversity.

For a particular year class, the population of adult salmon is proportional to the number of salmon smolts successfully emigrating through the Delta. That is, there is no "density dependence" in or downstream of the Delta. If there were, the estimated amounts of water would be greater. In this article, density dependence was assumed not to occur.

Table 1 Summary of amount and cost of water to increase fish population by one percent using Delta water project requirements

		Water and cost associated with 1% increase in population under average flow conditions (af)[a]							
		Type of requirement							
Species	Critical period for requirement	Export curtailment (taf)	Cost (millions /year)[b]	River flow increase (taf)	Cost (millions/ year)[b]	Delta outflow increase (taf)	Cost (millions/ year)[b]	Cross channel gate closure	Comments
Sacramento fall-run salmon smolts (Newman-Rice analysis)	Apr–Jun	400	$40	1,800	$180	NA[c]	NA[c]	Increases survival by 40% as compared to open. No water cost unless water quality problems.	Values for export curtailment are for river flow of about 20,000 cfs, export rate of 4,000 cfs, and Cross Channel gates closed. Opening gates increases the amount by a factor of about 1.4. The amount of export curtailment required is proportional to river flow. Amount of river flow required decreases roughly proportionally with increasing export rate.
Sacramento fall-run salmon smolts (revised Newman analysis)	Apr–Jun	110	$11	110	$11	NA[c]	NA[c]	No benefit at about 20,000 cfs river flow. Benefits up to 50% for higher and lower flows.	Probably a better estimate than Newman-Rice. Required export curtailment increases more than linearly with increasing river flowrate. Required river flow decreases less than linearly with increasing export rate. Cross Channel gate effects may be anomalous.
Sacramento fall-run fry	Feb	—[d]	—[d]	310	$31	NA[c]	NA[c]	—[d]	This estimate required a number of assumptions, all of which were made such that the estimate would tend to be low.
Sacramento spring-run and late-fall-run smolts	Dec–Jan	550	$55	NA[c]	NA[c]	NA[c]	NA[c]	—[d]	This estimate is based on only six data points, only one of which drives the relationship. The data do not show a relationship between survival and river flow.
San Joaquin fall-run smolts	mid-Apr to mid-May	NA[c]	NA[c]	70	$7	NA[c]	NA[c]	NA[c]	The data show a relationship between river flowrate and survival, but this relationship may be driven by higher flows only. No relationship has been found relating survival with export rate with a barrier at the head of Old River when river flowrate is 7,000 cfs or less.
Splittail	Feb–May	NA[c]	NA[c]	NA	NA	60	$3	NA[c]	The relationship between splittail abundance and X2 is thought to be a surrogate for the actual relationship between splittail abundance and the amount of wetted vegetation to which splittail eggs attach. The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
Starry flounder 1-yr olds	Mar–Jun	NA[c]	NA[c]	NA	NA	50	$5	NA[c]	The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
Longfin smelt	Jan–Jun	NA[c]	NA[c]	NA	NA	80	$8	NA[c]	The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
American shad	Feb–May	NA[c]	NA[c]	NA	NA	140	$14	NA[c]	The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
Pacific herring	Jan–Apr	NA[c]	NA[c]	NA[c]	NA[c]	110	$11	NA[c]	The relationship between herring abundance and X2 is not statistically significant. The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
Crangon shrimp	Mar–May	NA[c]	NA[c]	NA[c]	NA[c]	60	$6	NA[c]	The relevance of this relationship is questionable. Crangon are one species of a group of shrimp, all of which occupy the same ecological niche. The abundance of the group is not related to X2. The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.
Striped bass larval survival	Apr–Jun	NA[c]	NA[c]	NA[c]	NA[c]	50	$5	NA[c]	The amount of extra outflow required for a 1% population increase is roughly proportional to the Delta outflow rate from which the increase is desired.

[a] All amounts of water are proportional to percent increase in population. For example, a 5% increase in San Joaquin River smolt population would require (7,000 x 5%/1%) = 350,000 acre-feet.

[b] Assuming water = $100 per acre-foot. The value of water varies depending on the type of year (wet or dry) and the place where the water supply effect occurs.

[c] NA means not applicable.

[d] Assume same as for fall-run smolts per Newman-Rice.

General Approach

For the past two or three decades, data have been collected on population levels (abundance) of fish living in Sacramento-San Joaquin Delta waters and on survival of salmon that migrate through the Delta. Correlations have been developed between abundance or survival and various factors. Among those factors are the ones listed above to which the requirements apply.

The correlations take the following form:

1. Abundance or survival = f(export rate, river flowrate, position of Cross Channel gates, value of X2, other factors such as temperature)

Of course, not all variables apply in each case. For example, the relationship for species linked to X2 is simply

2. Abundance = f(X2)

Using these relationships, the change in abundance or survival associated with a change in any one of the factors can be estimated. For example, using equation 1, we can estimate the change in abundance or survival associated with any assumed change in export rate. Further, if we know the number of days during which the change in export rate applies, we can estimate the total acre-feet of export curtailment that would have produced the change in abundance or survival.

From such estimates we can estimate the population change per acre-foot of water, or its reciprocal, the acre-foot of water per population change. Further, if we assign a dollar value to the water we can estimate the "cost-effectiveness" of these environmental requirements and compare them to the cost-effectiveness of other, "non-water" actions that might be taken to increase fish populations.

Note that these amounts of water do not necessarily result in a water supply loss equal to the amounts shown. Sometimes, the water supply loss can be made up later in the year (or "pre-made up" earlier in the year). Therefore, these amounts should be considered as a measure of the risk of water supply loss rather than a measure of the amounts sure to be lost.

Salmon Smolt Survival and Population

We are interested in changes in populations of fish. In some cases the relationships derived from data collected over the years provide such estimates. For example, we have correlations between the annual abundance of several estuarine species and the average value of X2 during the period that is important for each fish.

However, for salmon, we typically have correlations between the various factors and the survival of smolts migrating downstream through the Delta. In this paper, I assume that the number of adult salmon in the ocean (including those harvested) is proportional to the number of smolts leaving the Delta. This assumption is probably not always true. For example, in some years there might be enough food in the ocean for only a limited number of pre-adult salmon, say, for example, 100,000. So, no matter how many smolts left the Delta, no more than 100,000 pre-adults would be produced. This is a simple example of "density dependence." Occurrence of density dependence might also be more complex.

In this paper, I will assume no density dependence. Under that assumption, percent changes in survival through the Delta equate to percent changes in adult population, including harvest. If this assumption were incorrect, the estimates of acre-feet or dollars associated with a given percent population change would be higher than the estimates in this paper.

Also, in this paper I will estimate the amount of water associated with a one-percent increase in population (abundance or survival). This is not to say that one percent is a significant increase. Most experts would say that in this system, one percent is insignificant and certainly not measurable given normal fluctuations in population. One percent is used in this paper simply to provide a convenient way of proportioning amounts of water associated with more significant increases in population.

Sacramento Fall-run Salmon Smolts

Survival of Sacramento fall-run salmon smolts is a subject of ongoing analysis. I used two analyses. The first is a statistical analysis by Newman and Rice (1997). The second is a new analysis by Newman (2000). This new analysis is still in preliminary form, and my results based on that analysis are therefore preliminary and subject to change if Ken Newman revises his draft.

Newman-Rice Analysis

Approach

Newman and Rice used data from more than 80 mark-recapture experiments each involving release of tens of thousands of coded-wire tagged hatchery smolts at various locations in the Delta and recapture of those smolts at Chipps Island in the western Delta or in the ocean as adults. Richard Remington, a graduate student working under Ken Newman, translated the Newman-Rice analysis into an Excel spreadsheet. The spreadsheet calculates the ratio of survivals for any two "strategies." A strategy is a combination of, among other variables, Sacramento River flow rate, the ratio of export rate to the rate of total Delta inflow (the "export-inflow ratio"), whether the Cross Channel gates are closed or open, and the point at which smolts are released. Survivals are calculated between the release point and Chipps Island.

We are interested in the survival of smolts through the Delta, that is, between the City of Sacramento and Chipps Island in the western Delta. Therefore, the release point of interest is Sacramento.

We are also interested in the effect of exports, not the ratio of exports to inflow. Therefore, I developed a relationship between Sacramento River flow and total Delta inflow. It is a straight-line relationship. I forced the straight line through the origin to avoid a relationship that produced negative values of total inflow at low values of Sacramento River flow. The ratio of total Delta inflow to Sacramento River flow is 1.4312. Using that ratio, values of export rate and river flow can be transformed into estimates of the export-inflow ratio used in the spreadsheet.

The spreadsheet requires an entry for Collinsville salinity. Collinsville salinity varies with river flow rate. The spreadsheet contains a lookup table of Collinsville salinity values for various values of river flow rate.

The spreadsheet produces the ratio of survivals for two different strategies (that is, the ratio of survival for Strategy 2 to the survival for Strategy 1). We are interested in the absolute survival between Sacramento and Chipps Island. Therefore, I chose the release point of Sacramento for Strategy 2. For Strategy 1, I chose conditions that should produce a survival as close to 1.0 as possible, namely, a release at Ryde with river flowrate of 30,000 cfs. Newman and Rice assumed that survivals from Ryde to Chipps Island were not affected by Cross Channel gate closure or by exports.

Assume, for the present, that survival from Ryde to Chipps Island is 1.0. (I will re-visit this assumption later.) With this assumption, survival from Sacramento to Chipps Island is equal to the spreadsheet's ratio of Strategy 2 survival to Strategy 1 survival. Therefore, the spreadsheet can be used to estimate smolt survival through the Delta (from Sacramento to Chipps Island) for various combinations of river flowrates, export rates, and Cross Channel gate closures.

Results

The following conclusions can be drawn from this analysis:

- Survivals with the Cross Channel gates closed are typically about 1.4 times survivals with the gates open.
- Therefore, closing the Cross Channel gates improves survival by about 40% at all values of river flow rate and exports.

For a one-percent increase in survival, the required changes in export rate can be estimated. Assuming these changes in export rate apply for the three months, April through June (91 days), that most smolts are emigrating, the total acre-feet of export curtailment associated with a one-percent increase in smolt survival can be estimated. These values are shown in Table 2.

These are large amounts of export reduction associated with only a one-percent increase in survival. The "efficiency" of this action (curtailing exports) could be improved if it were applied only when most of the smolts were in the Delta. Say, for example, that, 50% of the smolts emigrated through the Delta in three weeks. If this peak in migration could be identified and if exports were curtailed only for those 21 days, then the corresponding export reductions for a one-percent increase in smolt survival for the entire emigrating population would be about one-half those shown in Table 2.

Table 2 Decrease in total export amount associated with a one-percent increase in Sacramento fall-run smolt survival (using Newman-Rice analysis)

	Decrease in export amount (af)	
Sacramento River flow (cfs)[a]	*Cross channel gates closed*	*Cross channel gates open*
5,000	81,000	Not applicable
9,000	143,000	195,000
13,000	198,000	277,000
17,000	256,000	360,000
21,000	313,000	434,000
25,000	368,000	530,000
30,000	450,000	632,000
40,000	601,000	819,000
50,000	721,000	1,030,000
60,000	858,000	1,335,000

[a] Estimates based on assumed survival from Ryde to Chipps Island of 1.0. If a more realistic value of, say, 0.8 were assumed, all of these estimated amounts of river flow would increase by 25%. All numbers are rounded to the nearest thousand.

The amount of export curtailment is proportional to the percent increase in survival. Therefore, referring to Table 2, the amount of export curtailment for a 5% increase in survival at a river flowrate of 21,000 cfs with the Cross Channel gates closed would be:

5 x 313,000 = 1.56 million acre-feet.

The relationship between river flow and survival was similarly analyzed. Table 4 shows the increases in acre-feet of river flow associated with an increase in survival of one percent with the Cross Channel gates closed. These amounts of water are also proportional to the desired percent increase in survival. For example, a 5% increase in survival with river flowrate in the range of 9,000 to 13,000 cfs and exports at 2,000 cfs would be associated with a river flow increase of about 4 million acre-feet.

Recall that all of these results are based on the assumption that survival from Ryde to Chipps Island is 1.0. In fact, this survival is probably closer to 0.8. If it were 0.8, all of the estimated amounts of water would have to be adjusted by the ratio of 1.0 to 0.8. That is, all estimates would be increased by 25%.

Revised Newman Analysis (Preliminary Results from Ken Newman)

Approach

Ken Newman re-analyzed the relationships between survival and various factors. At the suggestion of Pat Brandes, U.S. Fish and Wildlife Service, he used only those coded wire-tagged release and recapture data from “paired releases.” This technique eliminates the influence of certain confounding factors such as sampling efficiency.

At the time this paper was being prepared, Newman’s analysis was still preliminary, and the results presented herein should be regarded as preliminary.

Newman developed the following two equations describing the relationship between survival and various factors:

3. $S = e^f/(1 + e^f)$

where,

4. $f = -6.4917 + 0.1148(\text{Sac}) + 0.5888(\text{Court}) + 1.4004(\ln[\text{Sac Flowrate}]) - 0.0960(\text{Release Temp}) - 1.9878(\text{Export:Inflow ratio}) - 0.6589(\text{Gate})$

where,

e = the base for natural logarithms,

Sac = 1 for release at Sacramento,
0 otherwise

Court = 1 for release at Courtland,
0 otherwise

ln Sac Flowrate = natural log (base e) of Sacramento River flowrate in cfs

Release Temp = temperature of river water at the time of release in °F

Export/Inflow ratio = ratio of export rate to delta inflow rate

Gate = 1 for Cross Channel gate open,
0 for closed

Results

Using equations 3 and 4, survivals from Sacramento to Chipps Island were estimated for various combinations of Cross Channel gate closures, Sacramento River flowrate, and export rate. Table 3 shows the amount of export curtailment associated with a one-percent increase in smolt survival, assuming export curtailments occurred for 91 days (April through June). Table 4 shows the increase in river flow associated with a one-percent increase in survival.

Estimates of total export curtailment associated with a one-percent increase in survival are generally lower using the revised Newman analysis.

Table 3 Decrease in total export amount associated with a one-percent increase in Sacramento fall run smolt survival (using revised Newman analysis)

	Decrease in export amount (af)	
Sacramento River flow (cfs)	*Cross channel gates closed*	*Cross channel gates open*
5,000	43,000	67,000
7,500	48,000	68,000
10,000	56,000	72,000
12,500	67,000	78,000
15,000	80,000	86,000
20,000	110,000	110,000
30,000	200,000	160,000
40,000	330,000	240,000
50,000	510,000	350,000

Table 4 Extra river flow (acre-feet) associated with a one-percent increase in Sacramento fall run smolt survival (Using Revised Newman analysis)

Sacramento River flow (cfs)	*Export Rate (cfs)*					
	0	*1,500*	*3,000*	*5,000*	*7,500*	*10,000*
5,000	36,000	33,000	33,000	37,000	46,000	63,000
7,500	40,000	36,000	35,000	37,000	42,000	51,000
10,000	51,000	45,000	41,000	39,000	39,000	42,000
12,500	65,000	57,000	52,000	47,000	43,000	43,000
15,000	91,000	80,000	72,000	64,000	57,000	52,000
20,000	146,000	130,000	117,000	103,000	90,000	81,000
30,000	240,000	218,000	199,000	177,000	155,000	137,000
40,000	439,000	406,000	376,000	341,000	303,000	271,000
50,000	588,000	549,000	513,000	470,000	422,000	381,000

Sacramento Fall Run Salmon Fry

Approach

Fry are salmon in the life stage between emergence from spawning gravel and 70 mm in length. Smolts are the next life stage, from 70 to 100 mm in length. Brandes and McLain (1999) found a correlation between abundance of salmon fry in the northern Delta and Sacramento River flow rate. Abundance is measured as the catch per cubic meter of water passing through the net for beach seines. The relationship is as follows:

5. Abundance = 0.000007 x Sacramento River Flowrate (cfs) + 0.2115

In other words, the higher the river flowrate, the more fry in the northern Delta.

This equation can be used along with several assumptions to estimate the amount of export curtailment and Sacramento River flow increase associated with a one-percent increase in fry abundance. The assumptions are as follows. Note that each assumption would tend to produce a low estimate of water associated with a one-percent population increase.

- There is no density dependence after the fry life stage.
- All fall run fry would be in the northern Delta at river flowrates of about 100,000 cfs or above, corresponding to a catch per cubic meter of about 1.0.
- The total number of fall run fry in the Sacramento system is independent of river flowrate.
- The amount of export curtailment or increased river flow associated with a one-percent increase in the number of smolts surviving from Sacramento to Chipps Island is the same as that associated with a one-percent increase in number of fry surviving.

With these assumptions, the values for catch per cubic meter from equation 5 fortuitously become estimates of the fraction of total fry in the northern Delta. Therefore, the amount of export curtailment or increased river flow associated with a one-percent increase in survival of the total fry population can be roughly estimated. This estimate is derived by dividing the export or flow estimates developed for smolts by the fraction of fry in the northern Delta, which is assumed equal to the abundance values from equation 5.

Results

Table 5 shows the estimates for export curtailments associated with a one-percent increase in survival of Sacramento fall-run fry. Increases in river flow associated with a one-percent increase in fry survival would be similarly higher than those for smolt survival.

Note that this analysis assumes that fry in the Delta (as opposed to upstream) suffer greater mortality than fry that remain upstream and that some of this greater mortality is associated with exports. This assumption, while environmentally conservative with respect to export effects, may not be correct. If it is not, then the amount of export curtailment associated with a one-percent increase in fry survival would be greater (perhaps much greater) than shown in Table 5.

Table 5 Decrease in total export amount associated with a one-percent increase in Sacramento fall run fry survival (Using Revised Newman Analysis)

	Decrease in export amount (af)	
Sacramento River flow (cfs)	*Cross channel gates closed*	*Cross channel gates open*
5,000	174,000	131,000
7,500	182,000	124,000
10,000	199,000	119,000
12,500	224,000	115,000
15,000	253,000	111,000
20,000	313,000	112,000
30,000	474,000	99,000
40,000	671,000	95,000
50,000	908,000	93,000

Sacramento Late-fall and Spring-run Salmon Smolts

Approach

This analysis is based on data from recent December and January experiments on the effect of export rate on smolt survival. The data are shown in Figure 1.

Figure 2 is a schematic showing the relative position of important locations.

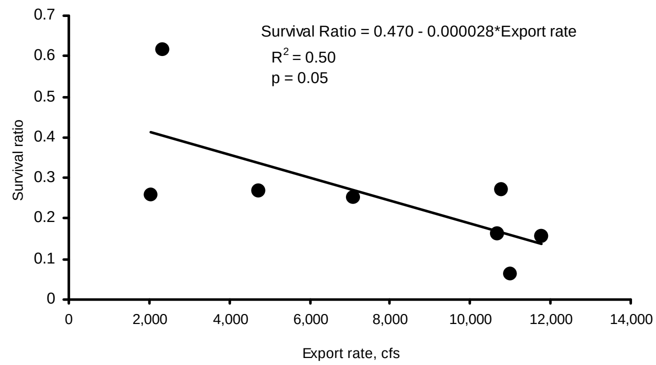

Figure 1 Relationship between export rate and the Georgiana-Ryde survival ratio

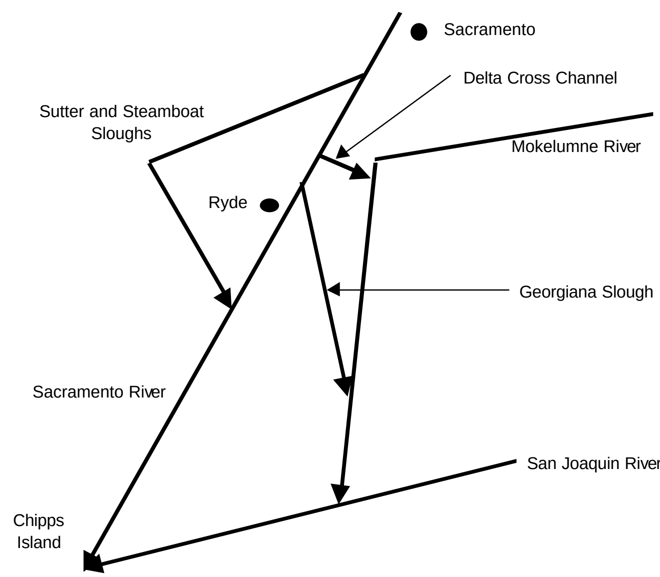

Figure 2 Schematic of locations for December and January survival experiments

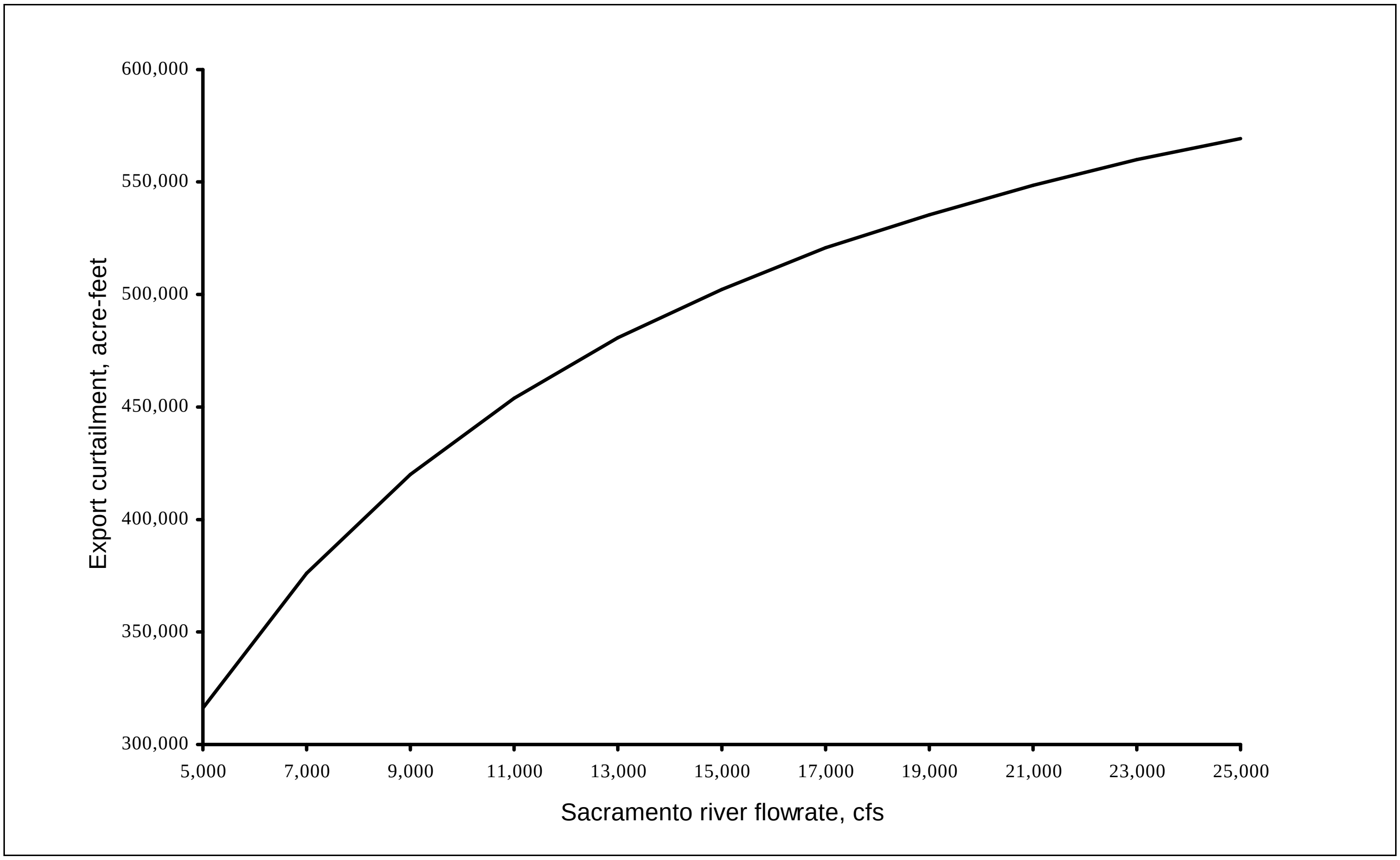

Figure 3 December-January export curtailment associated with a one percent increase in survival of late fall or spring run smolts through the Delta (Delta Cross Channel gates closed)

These experiments produced data relating export rate to the ratio of two survivals, one being the survival for smolts released at the north end of Georgiana Slough and recaptured at Chipps Island and the other being the survival of smolts released at Ryde and recaptured at Chipps Island. We are interested in the effect of export rate on survival from Sacramento to Chipps Island. Therefore, I transformed the data on survival ratios to data on survival from Sacramento to Chipps Island as follows.

I assumed that the survival from Ryde to Chipps Island is 0.8. I assumed that the Cross Channel would be closed.

I assumed that the fraction of smolts passing Sacramento and entering Georgiana Slough would be 0.58 times the fraction of flow entering Georgiana Slough. Hanson (1995) found that when 23% of flow entered Georgiana Slough, 14% of smolts did. When 49% of flow entered, 27% of smolts did. The average percent of smolts as a percent of flow is 58%. The flow entering Georgiana Slough with the Cross Channel Gate closed is 0.133 x Sac Flow + 829 cfs.

Therefore, the fraction of flow entering Georgiana Slough is 0.133 + (829 cfs/Sac Flow).

Taking 58% of this quantity = 0.077 + (481 cfs/Sac Flow) = fraction of smolts entering Georgiana Slough.

Note that this fish-flow-split assumption ignores those smolts that enter Steamboat and Sutter sloughs. Had those smolts been accounted for, the export curtailments associated with a one-percent increase in survival would be higher than estimated here.

Figure 3 shows the amount of export curtailment associated with a one-percent increase in smolt survival, assuming that exports would be curtailed for 62 days (December and January). These estimates are proportional to the desired percent increase in survival. The data, albeit limited, do not indicate a relationship between river flow rate and survival.

San Joaquin River Fall-run Smolts

Approach

Paired release data have been collected since 1989. Some of these data were collected when, during the time of the experiment, either export rate or river flowrate varied considerably around the median values shown. Nevertheless, as will be shown below, the data do show an apparent relationship between smolt survival and river flow rate, so the data were at least adequate to reveal that relationship.

Paired release data produce a ratio of survivals for two groups of smolts, one released at an upstream release point (Mossdale, Dos Reis, or Stockton) and recaptured at Chipps Island, and the other released at Jersey Point and recaptured at Chipps Island. The survival for the upstream release is divided by the survival for the Jersey Point release to produce a survival ratio.

Note, however, that unless the mortality between Jersey Point and Chipps Island were zero (survival = 1.0), which it would never be, this survival ratio would be an overestimate of actual survival between the upstream location and Chipps Island.

From all these paired releases I selected those that best represented actual future conditions, namely, a barrier at the head of Old River when river flowrates were below about 7,000 cfs and no barrier when flowrates were higher. We are interested in survival between Mossdale and Chipps Island under those conditions. Therefore, we can use the following data:

- For San Joaquin River flowrate at Vernalis <7,000 cfs:

  Mossdale releases with barrier

  All Dos Reis releases (with flow rate <7,000)

  All Stockton releases (with flow rate <7,000)

- For San Joaquin River flowrate at Vernalis >7,000 cfs:

  Mossdale releases without barrier

According to those rules, the data shown in Table 6 represent realistic future conditions.

Table 6 San Joaquin River paired release data for fall run smolt survival

Release location	*Release date*	*Absolute survival*	*Old River barrier in*	*Median San Joaquin River flow at Vernalis (cfs)*	*Total exports*	*Median San Joaquin River flow at Stockton (cfs)*
Dos Reis	4/20/89	0.162	no	2,240	10,020	47
Dos Reis	4/16/90	0.063	no	1,300	5,657	23
Dos Reis	5/2/90	0.034	no	1,293	2,248	282
Dos Reis	4/15/91	0.092	no	907	4,686	–35
Dos Reis	5/1/96	0.07	no	6,635	1,601	2,581
Dos Reis	5/1/96	0.117	no	6,496	1,551	2,528
Dos Reis	4/29/97	0.181	yes	5,965	2,282	2,235
Dos Reis	4/29/97	0.301	yes	5,965	2,282	2,235
Dos Reis	5/8/97	0.281	yes	5,770	2,291	2,151
Mossdale	4/17/95	0.402	no	18,675	3,706	7,442
Mossdale	4/16/98	0.306	no	21,317	1,893	8,700
Mossdale	4/23/98	0.153	no	17,950	1,916	7,291
Mossdale	4/26/94	0.133	yes	2,560	1,533	885
Mossdale	4/28/97	0.183	yes	5,938	2,280	2,224
Stockton[a]	5/6/91	0.141	no	1,082	4,409	244
Stockton[a]	5/11/91	0.112	no	835	3,138	174

[a] Actual release site was Buckley Cove.

Results

I performed several statistical analyses on these data in an attempt to find relationships between an estimate of absolute survival and river flow rate or export rate. I found a statistically significant relationship between absolute survival and river flow rate at both Vernalis and Stockton. I found no such relationship with export rate, despite having a wide range of export rates at lower river flow rates, as shown in Figure 4. I tried to find such a relationship using only data from low river flowrates, but was unsuccessful. I also tried an arc sine transformation of the absolute survival data to ensure a normal distribution (Sokal and Rohlf 1995) This transformation had no effect on the conclusions drawn from the statistical analysis.

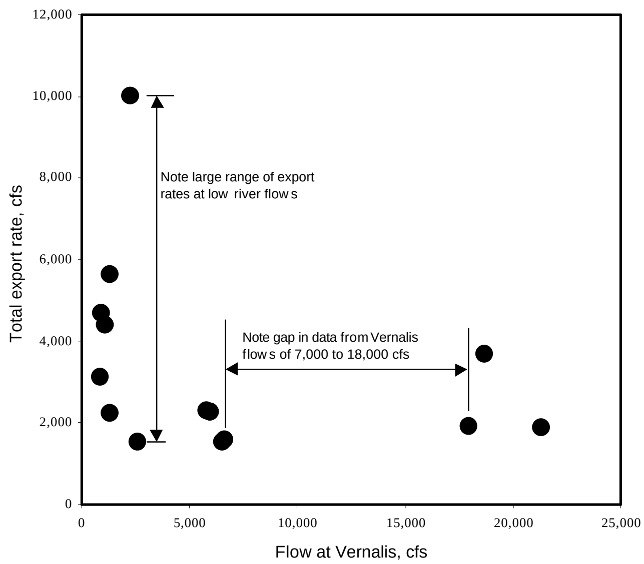

Figure 4 Range of data used in analysis of San Joaquin River fall-run smolt survival

The relationship of smolt survival to river flow rate at Vernalis is shown in Figure 5. From this relationship, the amount of increase in river flow rate associated with a one-percent increase in smolt survival can be estimated. This increase is about 1,000 cfs or, assuming the increase is necessary for 28 days, 55,400 acre-feet.

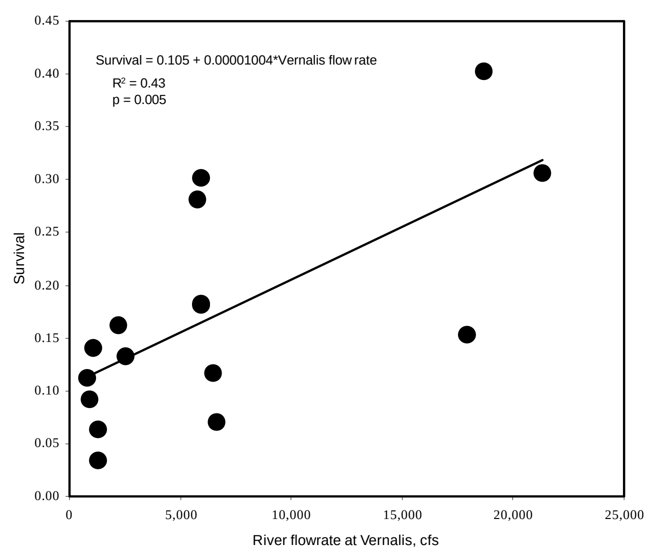

Figure 5 Relationship between survival of San Joaquin River fall-run smolts and river flow rate at Vernalis

Recall the assumption that survival from Jersey Point to Chipps Island was 1.0. Because this survival is, in fact, less than 1.0, the above estimate of water associated with a one-percent increase in smolt survival is low. If, for example, survival from Jersey Point were actually 0.8, the estimated river flow increase associated with a one-percent increase in survival would be about 70,000 acre-feet, assuming that the increase occurred for 28 days.

Direct Mortality of Salmon Smolts

Approach

The analyses above are for combined “direct” and “indirect” mortality. Direct mortality is mortality within the export facilities. It includes, for example, predation in Clifton Court Forebay. Indirect mortality is mortality that occurs elsewhere in the Delta. Indirect mortality is thought to increase as exports increase.

Over the years, hundreds of thousands of smolts have been grown in hatcheries, tagged with a small coded wire, then released at various locations in or upstream of the Delta. The smolts are recaptured downstream, typically at Chipps Island in the western Delta. Others are recovered as adults from the ocean fishery. Some are salvaged at the Delta export pumping plants. From the number salvaged, estimates are made of direct mortality, the number that died within the export facilities.

Table 7 summarizes data from 1993 through 1998 on the percent of emigrating, hatchery grown, coded wire-tagged smolts suffering direct mortality. Comprehensive data on direct mortality for coded wire-tagged release groups do not exist before 1993. However, data from a few release groups indicate that direct mortalities were higher for San Joaquin River salmon before 1993. (Chadwick, personal communication, see “Notes”) Note that the direct mortality numbers in the table are in percent.

Results

Note that the numbers in Table 7 are small. These data were collected independently of the data used in the relationships described above. These data indicate that direct mortality is a very small percent of the total mortality of emigrating smolts. To the extent that the analyses above indicate that export rate and river flow rate have a small effect on the sum of direct and indirect mortality, these data are consistent with that conclusion.

Table 7 Percent of all tagged salmon smolts released during 1993-1998 that suffered direct mortality at export pumps

						Percent direct mortality per release group					
						Tracy Pumping Plant			*Banks Pumping Plant*		
River system[a]	*Source of fish*[a]	*Race of salmon*	*Release location*[a]	*No. of release groups*	*Ave. no. of fish per group*	*Min.*	*Ave.*	*Max.*	*Min.*	*Ave.*	*Max.*
SR	CH	Late-fall run	CH	59	68,900	0.00	0.02	0.16	0.00	0.34	2.08
SR	CH	Late-fall run	D	17	39,000	0.00	0.07	0.35	0.00	1.76	10.30
SR	CH	Winter run	CH	104	1,600	0.00	0.00	0.00	0.00	0.00	0.19
SR	CH	Fall run	CH	75	50,900	0.00	0.00	0.03	0.00	0.00	0.09
SR	FRH	Fall run	FRH	29	51,500	0.00	0.00	0.00	0.00	0.00	0.00
SR	FRH	Fall run	D[b]	99	41,600	0.00	0.23	1.87	0.00	0.13	1.43
SR	FRH	Spring run	D[b]	2	49,600	0.00	0.01	0.02	0.00	0.13	1.43
SR	Trapped wild fish	Spring run	Butte and Mill creeks	9	1,800	0.00	0.00	0.00	0.00	0.00	0.00
SJR	MH	Fall run	MH	74	27,700	0.00	0.51	2.22	0.00	0.69	8.32
SJR	MH	Fall run	D[c]	21	34,700	0.00	0.11	0.77	0.00	0.10	0.65

[a] Abbreviations: SR-Sacramento River, SJR-San Joaquin River, CH-Coleman Hatchery, FRH-Feather River Hatchery, MH-Merced Hatchery, D-Delta.
[b] Consists of releases into the Sacramento River near Sacramento and downstream in the Delta.
[c] Consists of releases into the San Joaquin River near Mossdale and downstream in the Delta.

Estuarine Species Whose Abundance Is Associated with X2

Approach

In 1993 the San Francisco Estuary Project convened a workshop (Schubel 1993). This workshop produced a report that included data showing a relationship between abundance of certain estuarine species and the value of X2 in the spring, generally, February through June. X2 is the distance in kilometers from the Golden Gate Bridge to the location of the place in the estuary where salinity is 2 parts per thousand at the bottom. The location of the 2 ppt salinity line typically ranges between 50 and 80 km from the Golden Gate Bridge, that is, from just west (downstream) of Martinez to Collinsville.

These relationships became the basis for the X2 requirement, which was adopted by the State Water Resources Control Board. It mandates that the location of the 2 ppt salinity line (that is, the value of X2) be maintained at certain positions depending on how much runoff there is in the Central Valley watershed. The location of the 2 ppt salinity line, measured as X2, is controlled by Delta outflow. The higher the outflow, the farther downstream the 2 ppt salinity line is and the lower the value of X2.

Therefore, the X2 requirement is also a requirement for Delta outflow. Under certain conditions, typically in the spring of drier years, the X2 requirement controls Delta water project operations. Then, water project operators must either release water from upstream reservoirs or curtail exports or carry out some combination of these two actions. Either action can result in water supply reductions, unless the reductions can be made up later in the year.

The X2-abundance relationships were further developed by Jassby and others (1995) and then refined by Kimmerer (1998). Miller and others (1999) presented data on the status of these relationships since 1987.

Kimmerer (1998) among others, showed that the relationship between log abundance of seven estuarine species and X2 is linear. From Jassby and others (1995) we know that the relationship between X2 and steady-state Delta outflow is linear, that is, of the following form:

6. X2 = (a + b) x log(Delta outflow).

Therefore, the relationship between log abundance and log Delta outflow is linear. That is,

7. log(abundance) = (a + b) x log(Delta outflow).

Making use of this fact, I was able to estimate “a” and “b” for each of the seven species whose abundance has been associated with the value of X2 during the period February through June. (Note that there are no statistically significant relationships between X2 and either delta smelt or salmon.) Knowing “a” and “b,” I was able to estimate the change in Delta outflow associated with a one-percent increase in abundance for each species. The amount of additional outflow associated with a one-percent increase in abundance varies with the species and the initial outflow.

Each species has a different “critical period,” consisting of those months when X2 (or Delta outflow) is thought to be of most importance. These months were identified by both Jassby and others (1995) and Kimmerer (1998). The change in Delta outflow associated with a one-percent change in abundance was assumed to occur over those months for each species.

Also, there is an unresolved dispute over which historical data best describe the relationships between abundance and the value of X2. The arrival of the Asian clam in 1987 significantly altered the ecosystem in the western Delta and Suisun Bay, where the 2 ppt salinity line is usually located. Some would argue that only data collected after 1987 should be used. Others argue that all data should be used. I estimated the amount of additional outflow using both approaches.

RESULTS

Results are summarized in Table 8. This table shows the amount of additional Delta outflow associated with a one-percent increase in abundance in each species. The boldface numbers show data that are statistically significant. Note that the amount of additional outflow is proportional to both the desired percent increase in abundance and the initial Delta outflow. So, for example, a 5% increase in longfin smelt abundance at a Delta outflow of 5,000 cfs would be associated with

> 25,000 cfs x 5%/1% x 5,000 cfs/10,000 cfs = 62,500 acre-feet of additional Delta outflow.

Note that the X2 requirement typically controls Delta water project operations during drier periods, when Delta outflow tends to be low.

Because the critical periods overlap, the numbers are not additive. So, for example, the critical period for both splittail and American shad is the same, February through May. Therefore, an increase in Delta outflow for splittail would also benefit American shad and, for that matter, any of the other species whose critical period overlaps the period February through May.

If a minimum of at least a one-percent increase in abundance of all species were desired, the extra outflow would be about 94,000 acre-feet and about 190,000 acre-feet for Delta outflow rates of 10,000 cfs and 20,000 cfs, respectively.

Also note that some of the estimates shown in Table 8 are not statistically significant. This means that the *p* values (levels of significance) in the correlations of log abundance against log Delta outflow were markedly greater than 0.05, the typical upper limit in statistical analyses.

Table 8 Increase in Delta outflow associated with a one-percent increase in abundance of selected estuarine species

		Extra outflow associated with a 1% increase in abundance (af)[a]				
		Assumed initial Delta outflow (cfs)				
		Based on post-1987 data only		*Based on all historical data*		
Species	*Critical period*	*10,000*	*20,000*[b]	*10,000*	*20,000*[b]	*Comments*
Splittail	Feb–May	56,000	113,000	30,000	58,000	The relationship between log splittail abundance and log Delta outflow (or X2) is statistically different for the pre-1988 and post 1987 periods. Also, the relationship is not statistically significant for post-1987 data. Therefore, the 1% increase in abundance is unlikely to occur as a result of the increase in Delta outflow shown.
Starry flounder	1-year olds	35,000	69,000	**25,000**[c]	**51,000**	The pre-1988 and post-1987 relationships are not statistically different. Therefore, all the data should be used. These data show that changes in X2 or log outflow are associated with about one-third of the change in log abundance, the rest of the change being due to other factors.
Longfin smelt	Jan–Jun	**39,000**	**78,000**	25,000	50,000	The pre-1988 and post-1987 relationships are statistically different. The post-1987 relationship is statistically significant. Changes in X2 or log outflow in the post-1987 period are associated with about 60% of the changes in log abundance.
American shad	Feb–May	**71,000**	**142,000**	57,000	114,000	The pre-1988 and post-1987 relationships are marginally statistically different. Changes in X2 or log outflow in the post-1987 period are associated with about one-third of the changes in log abundance.
Pacific herring	Jan–Apr	57,000	114,000	57,000	114,000	Neither the pre-1988 nor the post-1987 relationships nor the relationship using all data are statistically significant. Therefore, the 1% increase in abundance is unlikely to occur as a result of the increase in Delta outflow shown.
Crangon shrimp	Mar–May	31,000	62,000	**30,000**	**60,000**	The pre-1988 and post-1987 relationships are not statistically different. Therefore, all the data should be used. These data show that changes in X2 or log outflow are associated with about half of the change in log abundance, the rest of the change being due to other factors. However, the relevance of this relationship is questionable; *Crangon* is only one of three species of caridean shrimp that play an equivalent role as a forage species.[d]
Striped bass	Larval survival	18,000	35,000	26,000	53,000	The pre-1988 and post-1987 relationships are statistically different. The post-1987 relationship is not statistically significant. Therefore, the 1% increase in abundance is unlikely to occur as a result of the increase in Delta outflow shown.

[a] The amount of extra Delta outflow required (in acre-feet) is proportional to both the initial Delta outflow and the desired percent increase in abundance.
[b] 20,000 cfs is a more typical Feb-June Delta outflow than 10,000 cfs. The 10,000 cfs data are presented as a convenient basis for proportioning required extra outflow.
[c] Bold indicates statistical significance.
[d] Remarks from Kathy Hieb, Department of Fish and Game, at the Spring 1998 X2 Workshop at Contra Costa Water District.

References

Newman K, Rice J. 1997. Statistical model for survival of chinook salmon smolts outmigrating through the lower Sacramento-San Joaquin system. Interagency Ecological Program Technical Report 59.

Newman K. 2000. Estimating and modeling survival rates for juvenile chinook salmon outmigrating through the lower Sacramento River using paired releases. 11 Jan 2000 draft report. Prepared for the California Department of Water Resources.

Brandes PL, McLain JS. 1999. Juvenile chinook salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. 15 Oct 1999 draft report.

Hanson CH. Evaluation of the response of juvenile chinook salmon to the flow split at the confluence between Georgiana Slough and the Sacramento River. 27 Oct 1995 draft memorandum.

Sokal RR, Rohlf FJ. 1995. Biometry, the principles and practice of statistics in biological research. W. H. Freeman & Co.

Schubel JR. 1993. Managing freshwater discharge to the San Francisco Bay-Delta Estuary: the scientific basis for an estuarine standard. San Francisco Estuary Project, U.S. Environmental Protection Agency.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as an habitat indicator for estuarine populations. Ecol Appl 5:272–89.

Kimmerer WJ. 1998. A summary of the current state of the X2 relationships. IEP Newsletter 11(4)14–25.

Miller WJ, Mongan TR, Britton A. 1999. Estuarine species abundance, X2, and Sacramento-San Joaquin Delta exports. IEP Newsletter 12(2):48–53.

Notes

Pete Chadwick. California Department of Fish and Game, retired. Personal communication with author in 1999.

Errata

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Two errors were discovered in the above-named article. This article was published in the spring 2000 issue of the *IEP Newsletter* (volume 13, number 2). In Table 2, on page 29 of that issue, the following corrections should be made:

- Pacific staghorn sculpin was observed in 1980–1983.
- Shimofuri goby was not observed in 1980–1983.

I apologize for any inconvenience that may have resulted from these errors.

ANNOUNCEMENTS

CALFED BAY-DELTA SCIENCE CONFERENCE OCTOBER 3–5, 2000 SACRAMENTO CONVENTION CENTER 1400 J STREET, SACRAMENTO, CALIFORNIA, USA

The CALFED Bay-Delta Science Conference will feature a plenary session, keynote address, concurrent technical sessions, and a poster session. The preliminary program below describes the themes and number (in parentheses) of oral presentations scheduled to date. Access the website for current information and electronic registration: http://www.iep.water.ca.gov/calfed/sciconf/.

Tuesday, October 3, 2000

Organic Carbon and Lower Trophic Level Processes (10): Dr. James T. Hollibaugh, University of Georgia

Climate Variability and CALFED (8): Dr. Mike Dettinger, U.S. Geological Survey

Levee System Integrity (9): Ms. Lauren Hastings, CALFED

Salmonids (10): Dr. Randy Brown, California Department of Water Resources

Species of Special Concern (15): Dr. Bill Bennett, U.C. Davis, and Dr. Peter Stine, U.S. Geological Survey

Drinking Water Quality (3): Ms. Elaine Archibald, Consultant to California Urban Water Agencies

Wednsday, October 4, 2000

Plenary Session: The Role of Science in CALFED, Mr. Steven Ritchie, CALFED

Keynote Address: Why CALFED Needs Ecological Detectives, Dr. Marc Mangel, U.C. Santa Cruz

CALFED Interim Science Board: A Balance Between Independent Review and Hands on Participation in Adaptive Management, Dr. Robert Twiss, Chair, CALFED Interim Science Board, U.C. Berkeley

Adaptive Management: Interface Between Research and Management, Dr. Michael Healey, CALFED Interim Science Board, University of British Columbia

Science and Water Management in California, Dr. Samuel Luoma, U.S. Geological Survey

Effects of Contaminants and Other Chemical Stressors (19): Ms. Valerie Connor, Central Valley Regional Water Quality Control Board, and Dr. Victor De Vlaming, State Water Resources Control Board

Fluvial Processes (13): Dr. Matt Kondolf, U.C. Berkeley

Effects of Nonnative Invasive Species (7): Ms. Kim Webb, U.S. Fish and Wildlife Service

Poster Session (more than 100 poster abstracts submitted): 4:00 to 7:00 PM, Dr. Peggy Lehman, California Department of Water Resources, and Mr. Bruce Thompson, San Francisco Estuary Institute

Thursday, October 5, 2000

Fish Facilities and Fish Screening (13): Mr. Dan Odenweller, California Department of Fish and Game, and Mr. John Andrew, California Department of Water Resources

Hydrodynamics (10): Dr. Jon Burau, U.S. Geological Survey

Tidal Wetland Processes (9): Dr. Larry Brown, U.S. Geological Survey

IEP TECHNICAL REPORT 65 PUBLISHED IN MAY 2000

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Proceedings of the Sixteenth Annual Pacific Climate Workshop, edited by G. James West and Lauren Buffaloe was published as IEP Technical Report 65 in May 2000.

Excerpt from the “Summary”:

> Impacts of the recent El Niño and La Niña have highlighted the need and potential to use climate information in societal activities and decisions. Thus, “Climate and Society” was the theme of the 16th annual Pacific Climate (PACLIM) workshop. PACLIM is a forum for exploring perspectives and developing insights into the interactions between climate and a broad range of disciplines in the geographic area encompassed by the Pacific Ocean and western Americas. This year’s meeting focused on implications of seasonal climate forecasts and historical information about climate in natural resources management and in evaluation of past and planned policies.

Copies of the proceedings may be obtained by contacting Lauren Buffaloe by phone or e-mail.

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

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For information about the Interagency Ecological Program, log on to our website at http://www.iep.water.ca.gov. Readers are encouraged to submit brief articles or ideas for articles. Correspondence, including submissions for publication, requests for copies, and mailing list changes should be addressed to Lauren Buffaloe, California Department of Water Resources, 3251 S Street, Sacramento, CA, 95816-7017.

■ Interagency Ecological Program for the San Francisco Estuary ■

IEP NEWSLETTER

Chuck Armor, California Department of Fish and Game, Program Manager & Editor
Zachary Hymanson, California Department of Water Resources, Editor
Lauren Buffaloe, California Department of Water Resources, Managing Editor

The Interagency Ecological Program for the San Francisco Estuary
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California Department of Water Resources	California Department of Fish and Game
State Water Resources Control Board	US Fish and Wildlife Service
US Bureau of Reclamation	US Geological Survey
US Army Corps of Engineers	US Environmental Protection Agency

National Marine Fisheries Service

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CONSIDER THAT ARTICLES HAVE NOT RECEIVED PEER REVIEW.